SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

B.O.D. of Chlorinated Sewage—Snow

Temperature Effects in Filters—Schroepfer, et al.

Biological Oxidation of Refinery Wastes—Coe

Phosphates in Lake Fertilization—Sawyer

Important NPA Action on Contruction—See Page 722

JUNE, 1952—VOL. 24, No. 6

Make Plans to Attend

SILVER ANNIVERSARY MEETING

OF THE

FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

IN CONJUNCTION WITH

NEW YORK SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

HOTEL STATLER
NEW YORK CITY

October 6-9, 1952

FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS
325 ILLINOIS BUILDING CHAMPAIGN, ILLINOIS

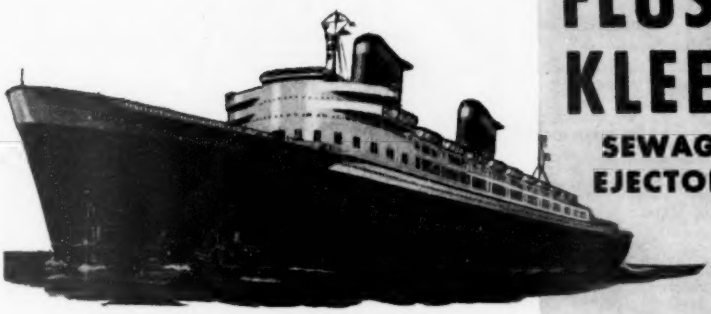
THE GREAT NEW AMERICAN FLAG SUPERLINER

S.S. UNITED STATES

IS EQUIPPED WITH

FLUSH KLEEN

SEWAGE EJECTORS



Built for United States Lines by the Newport News Shipbuilding and Drydock Company, Gibbs & Cox, Naval Architects under auspices of the United States Maritime Administration.

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FLUSH-KLEEN EJECTORS were selected on a proven record of ship performance . . . since 1936 they have been giving *trouble-free service, clog-proof operation* and *low-cost maintenance* on numerous troop transports, cargo ships, hospital ships, as well as on the "America", now our country's second largest passenger ship.

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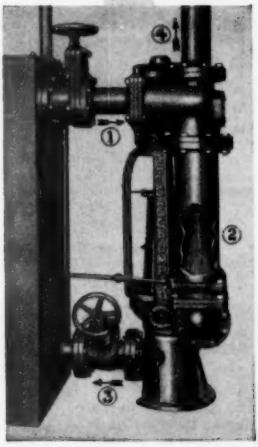
If you do not have all the facts about FLUSH-KLEEN EJECTORS, please request Bulletin No. 122—it will be sent to you promptly.

CHICAGO SEWAGE EQUIPMENT



The positive clog-proof operation of FLUSH-KLEEN EJECTORS is readily understood by referring to the cut-away illustration.

FILLING WET WELL—(1) Sewage flows through inlet pipe. (2) Sewage solids are retained by strainer. (3) Strained sewage flows through idle pump to basin.

PUMPING—(3) Strained sewage is pumped from basin. (2) Sewage solids are backwashed from strainer. (4) Special check valve closes; sewage and solids are pumped overboard.

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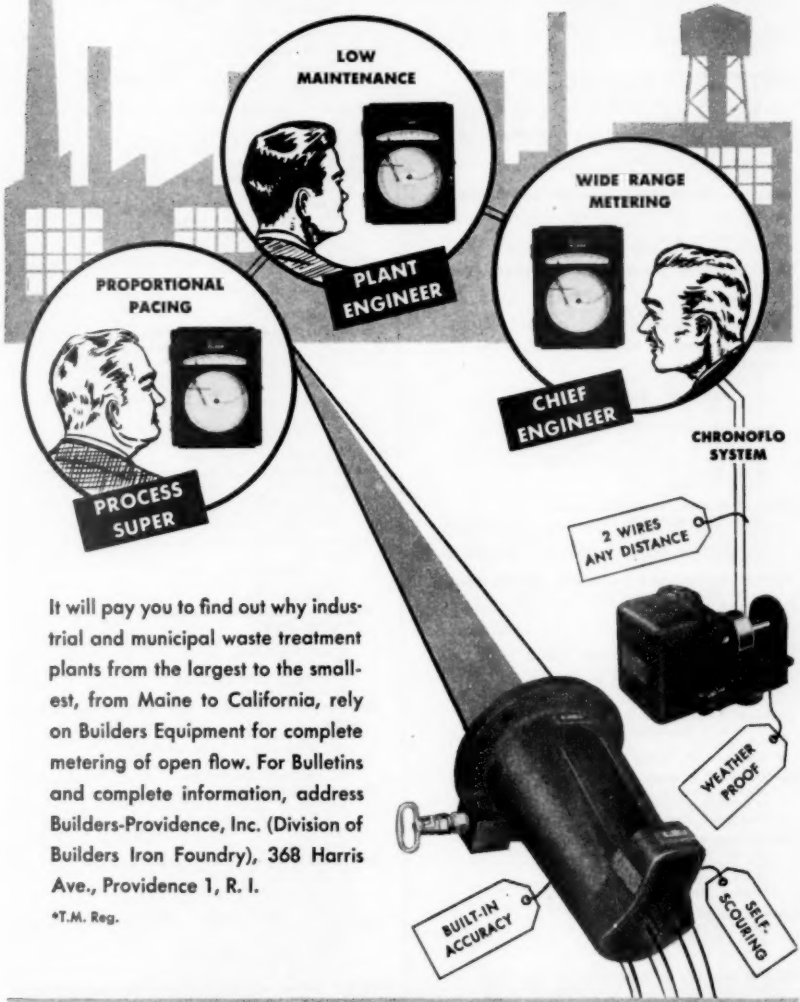

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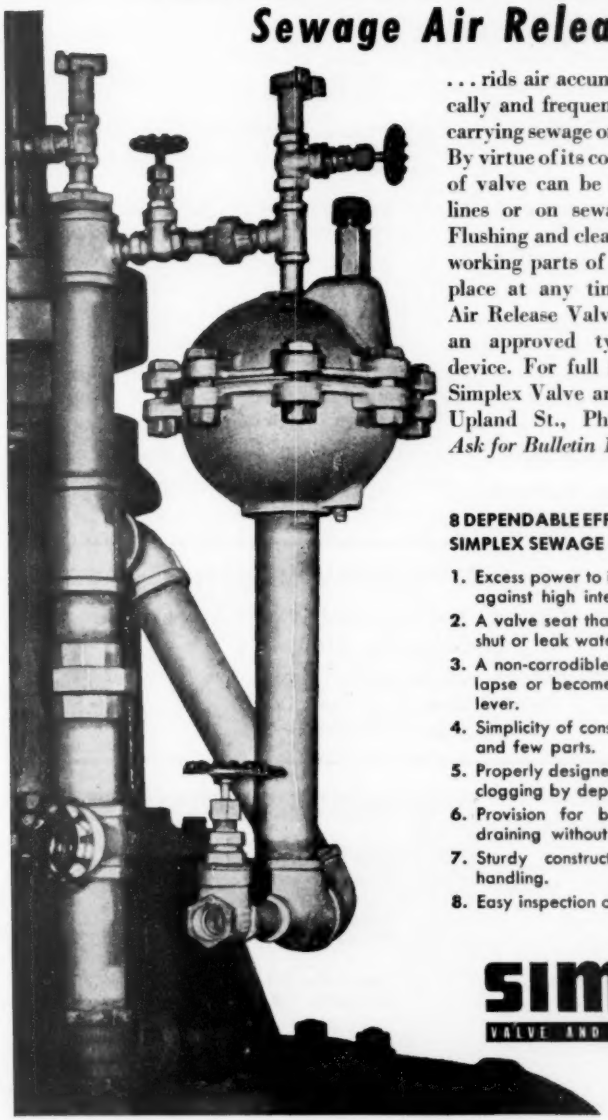

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Association	*Place*	*Time*
Central States Sewage and Ind. Wastes Assn.	Loraine Hotel, Madison, Wisc.	June 25–27, 1952
Pennsylvania Sewage and Ind. Wastes Association	Pennsylvania State College, State College, Pa.	Aug. 27–29, 1952
Iowa Sewage Works Association	Grinnell College, Grinnell, Iowa	Sept. 9–11, 1952
Rocky Mt. Sewage Works Assn.	Frontier Hotel, Cheyenne, Wyo.	Sept. 15, 1952
Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.	Andrew Johnson Hotel, Knoxville, Tenn.	Sept. 15–17, 1952
South Dakota Water and Sewage Works Conference	St. Charles Hotel, Pierre, So. Dakota	Sept. 17–19, 1952
German Sewage Technologists Assn.	Weisbaden, Germany	Sept. 17–20, 1952
Mo. Water and Sewerage Conference	Governor Hotel, Jefferson City, Mo.	Sept. 21–23, 1952

SILVER ANNIVERSARY MEETING

Federation of Sewage and Industrial Wastes Associations
in conjunction with
New York Sewage and Industrial Wastes Association
Hotel Statler, New York City
October 6–9, 1952

Pacific Northwest Sewage and Industrial Wastes Assn.	Multnomah Hotel, Portland, Ore.	Oct. 23–24, 1952
The Canadian Institute on Sewage and Sanitation	Seigniory Club, Montebello, Que.	Nov. 3–5, 1952
North Carolina Sewage and Industrial Wastes Assn.	Skyland Hotel, Hendersonville, N. C.	Nov. 10–12, 1952
Florida Sewage and Industrial Wastes Association	San Carlos Hotel, Pensacola, Fla.	Nov. 16–19, 1952

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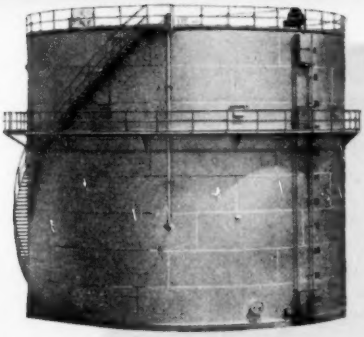

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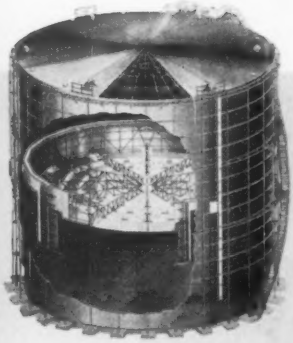

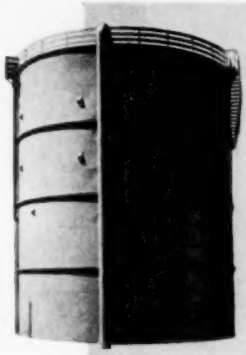

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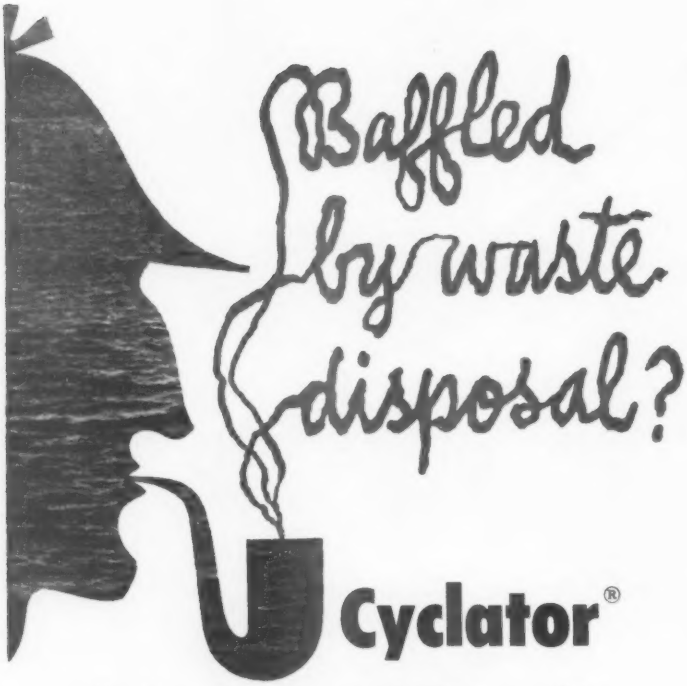

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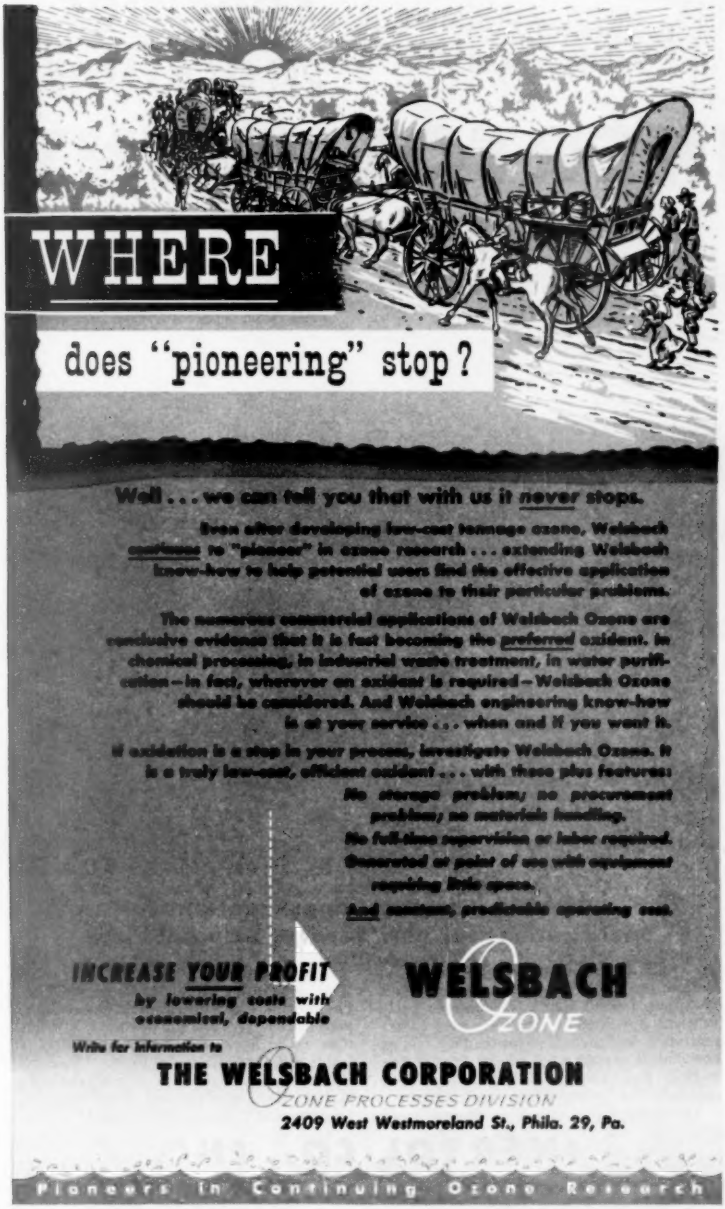
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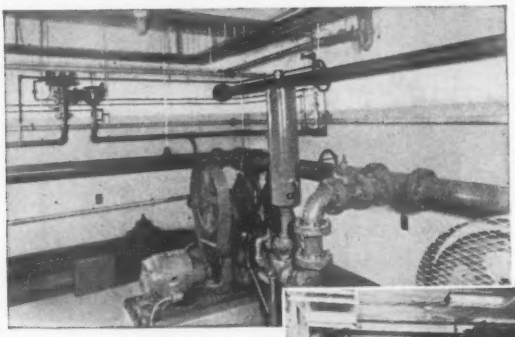

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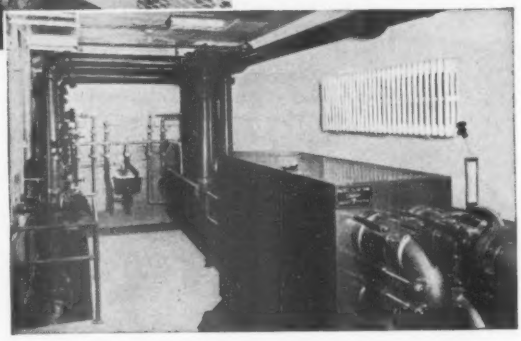

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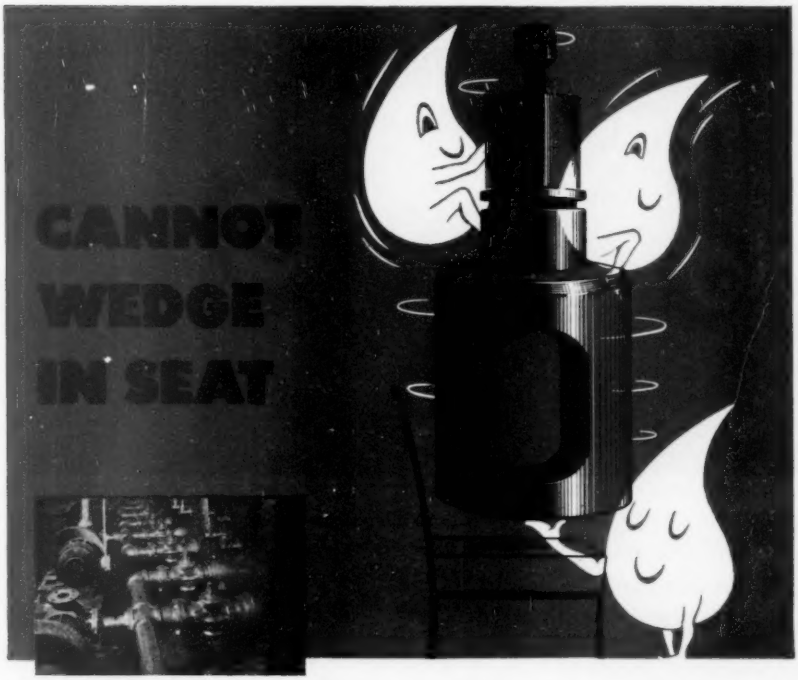

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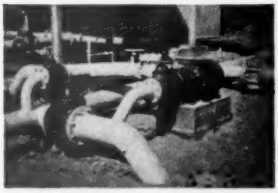

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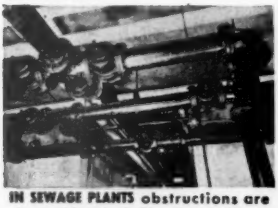

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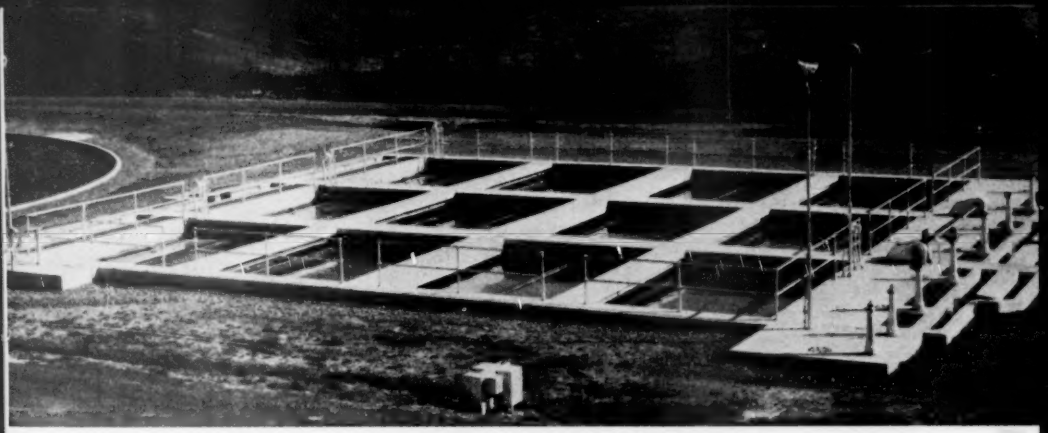

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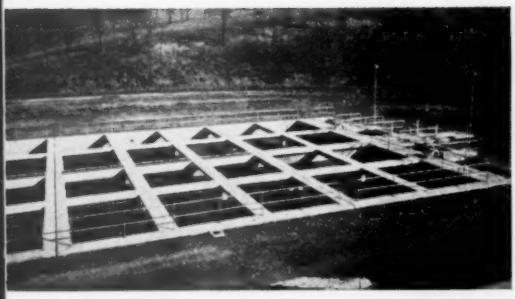

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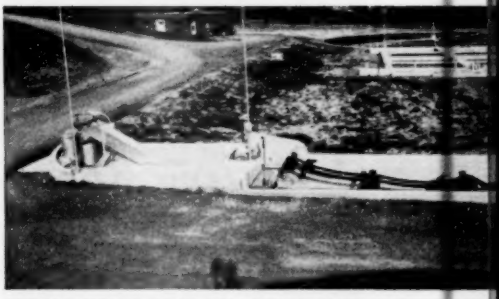

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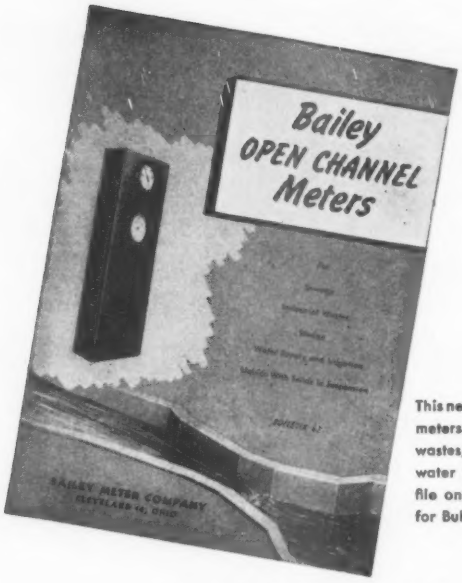

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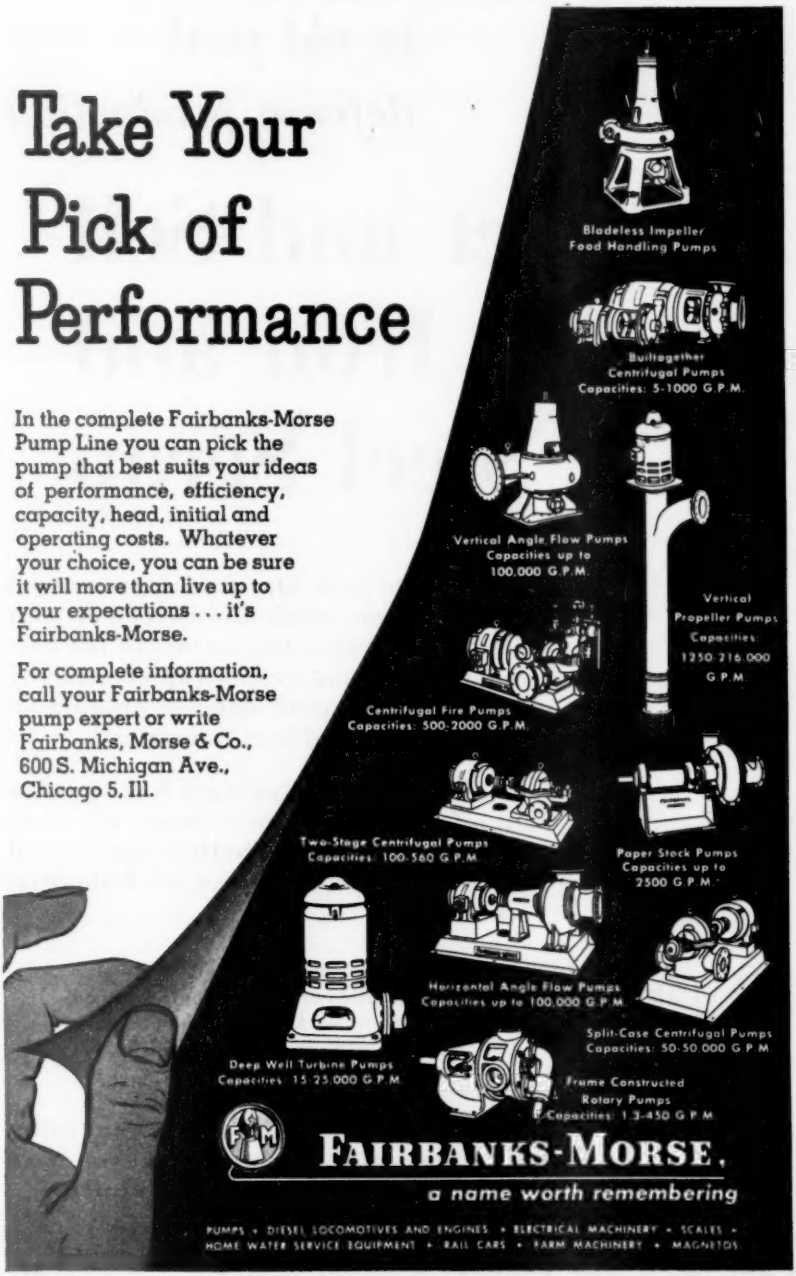
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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 24 | JUNE, 1952 | Number 6

Contents

Sewage Works

Biochemical Oxygen Demand of Chlorinated Sewage. By William Brewster Snow 689

Temperature Effects on Trickling Filters. By G. J. Schroepfer, M. B. Al-Hakim, H. F. Seidel, and N. R. Ziemke 705

Performance of High-Rate Trickling Filters Operated in Series and in Parallel. By H. Heukelekian, C. B. McMenamin, and M. C. Rand 723

Industrial Wastes

Bench-Scale Biological Oxidation of Refinery Wastes with Activated Sludge. By R. H. Coe 731

Chemical Oxidation of Phenolic Wastes with Chlorine. By N. S. Chamberlin and A. E. Griffin 750

Discussion by Grant A. Pettit 761

Rag, Rope, and Jute Wastes from Specialty Paper Mills. III. Chemical Treatment of Rope Cook Liquor. By Willem Rudolfs and N. L. Nemerow 764

Stream Pollution

Some New Aspects of Phosphates in Relation to Lake Fertilization. By Clair N. Sawyer 768

Viability of Coliform Organisms in Estuary Water. By T. C. Buck, Jr., C. E. Keefer, and Hester Hatch 777

The Operator's Corner

Sludge Disposal Experiences at Elizabeth, N. J. By Leslie E. West 785

1952 Report of the Committee on Qualifications of Sewage Works Operators 790

Tips and Quips 798

Reviews and Abstracts 801

Proceedings of Member Associations

FSIWA Member Association Formed in Nebraska 240a

Oklahoma Water, Sewage and Industrial Wastes Conference 242a

Equipment and Supply Lines 244a

W. H. Wisely, *Editor*, 325 Illinois Building, Champaign, Illinois
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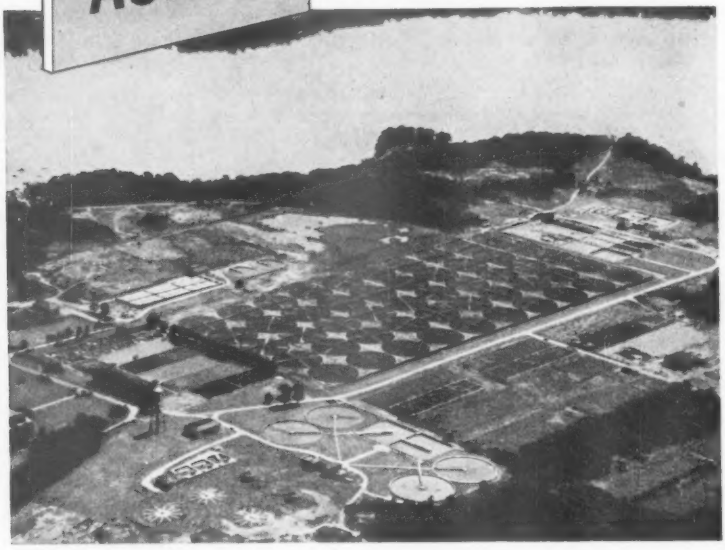

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Sewage Works

BIOCHEMICAL OXYGEN DEMAND OF CHLORINATED SEWAGE*

By William Brewster Snow

Associate Professor of Civil Engineering, Duke University, Durham, N. C.

Application of chlorine to sewage effects a reduction of B.O.D. which is generally considered to be real as well as apparent. Whether it is employed for the prevention of sulfide production in long sewer outfalls, for the avoidance of septicity, for the deodorization of foul sewage, or for the disinfection of sewage effluents, introduction of chlorine effects a reduction of B.O.D. concurrent with the accomplishment of these purposes.

A considerable amount of research was done during the late 1920's and the early 1930's on the reduction of B.O.D. by chlorine. From the early investigations, two criteria of accomplishment emerged and have been generally accepted: (1) that application of chlorine to sewage in concentrations sufficient to produce a trace of residual chlorine after 15 min. effects a reduction in the 5-day B.O.D. ranging from 15 to 35 per cent, and (2) that this reduction amounts to approximately 2 p.p.m. per p.p.m. of chlorine "absorbed."

More recently Griffin and Chamberlin (3) studied the amounts of chlorine required to effect the "breakpoint" reaction in raw and treated sewages and correlated these data with the observed reduction in the B.O.D. of the samples. They found, as had earlier investigators, that the largest increments in B.O.D. reduction result from increasing chlorine doses up to the level required to produce a slight 15-min. residual.

Chlorine reacts rapidly with the constituents of sewage during the first 15 min. of contact, the amount "absorbed" varying with the strength and the character of the sewage and with the chlorine concentration. The magnitude of the effect of chlorine concentration is illustrated by data of McLachlan and Gaillard (7), who showed in one series of samples that 7 p.p.m. of chlorine were absorbed out of an applied dose of 24 p.p.m. When the applied dose was doubled (to 48 p.p.m.) the amount of chlorine absorbed increased by a factor of 3 (to 22.5 p.p.m.) At an applied concentration of 143 p.p.m., the chlorine absorbed amounted to 57 p.p.m.

The reactions of chlorine with the materials in sewage are of three types:

1. Direct oxidation of reduced substances.—This type of reaction is characterized by the direct oxidation of hydrogen sulfide and other reduced substances. The rise in chlorine demand in anaerobic sewage is due to the elaboration of such reduced substances as a result of the biochemical activity of anaerobic organisms. The rate of reaction between these substances and chlorine is very rapid and is probably complete within a matter of seconds.

2. Substitution of chlorine for hydrogen.—When the substitution takes place on nitrogen atoms, chlor-

* Presented at 31st Annual Joint Meeting, North Carolina Sewage and Industrial Wastes Assn. and North Carolina Section, AWWA; Winston-Salem, N. C.; November 12–14, 1951.

amine type compounds are formed that possess bactericidal power of varying potency. The chloro-substituted products of ammonia (mono-, di-, and trichloramine) are relatively good bactericides, whereas the more complex compounds of this type show only slight bactericidal power. This gradation of bactericidal efficiency is approximately paralleled by the ability of these compounds to react with orthotolidine.

When the substitution of chlorine takes place on a carbon atom, the compounds formed have not been shown to be toxic to bacteria. However, Levine and Watkins (5) have shown that of nine species of bacteria capable of utilizing acetic acid as the sole source of carbon, only two showed moderate growth on chloro-acetic acid. This indicates that, although chlorine substitution on carbon atoms does not produce compounds that are toxic to bacteria, the chlorinated compounds may be more resistant to bacterial attack and, to that extent, are partially stabilized against biochemical decomposition.

3. Addition of chlorine to unsaturated compounds.—Tarbell (12) has shown that acids of the fumaric-maleic type add chlorine in dilute aqueous solution to form isomeric chlorohydrins. Because such di- and tri-carboxylic acids are essential steps in carbohydrate metabolism, the chlorination of them may result in a distinctly retarding or inhibitory effect on the normal course of decomposition of carbonaceous material.

Rate and Amount of B.O.D. Exerted

None of the published investigations of the reduction of the B.O.D. of sewage by chlorination have followed the daily course of the B.O.D. reaction and compared it, in terms of unimolecular parameters, with the course of the B.O.D. reaction in unchlorinated controls. The unimolecular equation is known to represent a good first approximation of the first stage of the B.O.D. reaction, although this fact does not signify a unimolecular mechanism. Ruchhoft (10) has pointed out that "this equation, when it applies, has very definite advantages: (1) it is dimensional; (2) it permits the description of the rate of change as represented by a B.O.D. series to be indicated by a single value, k; and (3) it fixes an apparent limit for the so-called ultimate demand."

In this work, the two parameters of the unimolecular formulation (the reaction velocity constant, k, and the ultimate first-stage B.O.D., L) provided an effective means of gaging the qualitative and quantitative changes in the decomposable material in chlorinated sewage samples.

A reduction in the 5-day B.O.D. of sewage as a result of chlorination, in terms of the unimolecular parameters, may result in one of three ways: (1) as a result of a reduction of the reaction velocity constant, k; (2) as a result of a reduction of ultimate first-stage demand, L; and (3) as a result of a reduction of both of these parameters.

In the first instance, a reduction of k would imply that as a result of chlorination a qualitative change in the character of the sewage constituents had taken place so that they had become less readily decomposable by aerobic organisms. Thus, a sewage having a k value of 0.20 will exert 90 per cent of its ultimate first-stage B.O.D. in 5 days. By comparison a sewage whose k value is only 0.15 will have exerted only 82 per cent of its B.O.D. in the same 5-day period. This 8.8 per cent reduction of 5-day B.O.D. would disappear as both sewages reached a point of ultimate first-stage B.O.D. satisfaction. This concept of B.O.D. reduction by chlorination is implicit in the papers of earlier investigators when they discussed whether such an observed 5-day B.O.D. reduction was "permanent" or not.

In the second instance, a reduction of L would imply that as a result of chlorination a quantitative change had taken place in the decomposable fraction of sewage. Such a change would be truly permanent reduction of B.O.D. and would manifest itself as a constant percentage reduction of each day's B.O.D. That is to say that, for a sewage whose L value was reduced by 10 per cent as a result of chlorination, the daily ordinates of the B.O.D. curve for chlorinated samples would be 10 per cent less than the corresponding ordinates for the unchlorinated control.

In the third instance, a reduction of both k and L by chlorination would imply both quantitative and qualitative changes in the decomposable organic matter in the sewage.

Methods

The critical problem in evaluating the B.O.D. of samples that have been chlorinated in excess of the chlorine demand has been to employ a dechlorination procedure that will eliminate all bactericidal chlorinated compounds and in which all of the dechlorinating agent is quantitatively oxidized by the chlorine, leaving no excess reducing agent to exert a subsequent oxygen demand. Sodium thiosulfate has frequently been employed as the dechlorinating agent. Dienert and Waldenbulke (2) have shown that the products of reaction between sodium thiosulfate and sodium hypochlorite include both sodium sulfate and sodium tetrathionate. The partially oxidized tetrathionate will exert an oxygen demand as shown by Barton and Krebs (1), who reported that 1 ml. of excess N/40 thiosulfate in 200 ml. of sewage produced a 2-p.p.m. increase in the 5-day B.O.D., whereas 1 ml. of excess N/40 sodium sulfite produced only a 1 p.p.m. increase in 5-day B.O.D.

Treadwell and Hall (13) state that the presence of sulfites can be demonstrated by their ability to decolorize malachite green. As a spot test, 1 drop of malachite green (20 mg. per liter) will be decolorized by 1 drop of solution containing 1 gamma * or more of sulfite; this would be equivalent to a 20-p.p.m. solution of sulfite. Weaker concentrations of sulfite will effect partial decolorization of malachite green that is visually detectable. The following dechlorination procedure was evolved and used throughout this work:

1. Samples of sewage a liter in excess of the amount needed were chlorinated to the desired concentration. At the end of the contact period, a portion of the sample (sufficient to prepare the necessary quantity of sewage dilution for bottling and incubation) was placed under a slowly-turning mechanical stirrer.

2. Crystalline sodium sulfite was added in small amounts. The crystalline form of the reducing agent was used to eliminate the necessity of dealing with a solution of changing normality and to avoid further dilution of the sample.

3. After each addition, time was allowed for solution of the crystals and reaction with the chlorine. Then an ortho-tolidine spot test was run. This procedure was continued until the faintest detectable color resulted.

4. One more addition of sulfite was made and the solution further tested with ortho-tolidine in a 50-ml. Nessler tube. When undiluted sewage was being tested, less than 50 ml. had to be used in order to read the color in the tube. In dechlorinating 3 per cent dilutions in the pre-incubation series of experiments, no difficulty from sewage turbidity was encountered in 50-ml. portions.

5. To detect presence of possible excess sulfite, 5 drops of malachite green solution were placed in each of four depressions on a porcelain plate. Five drops of the dechlorinated sample were added to the first and third of

* 0.001 mg.

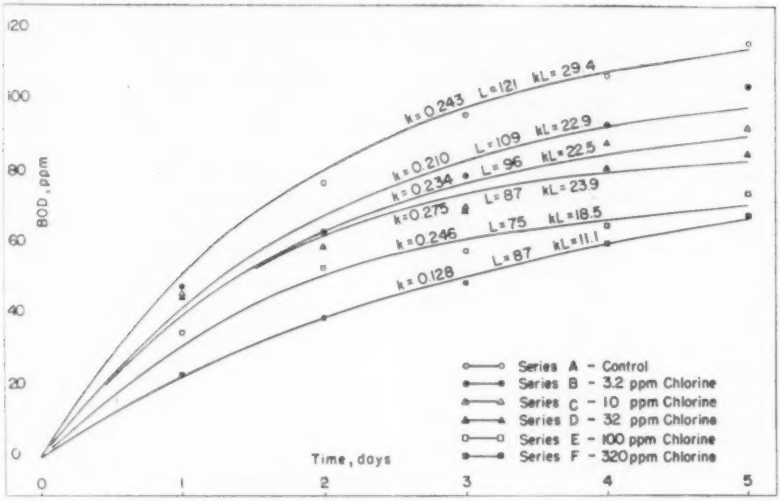

FIGURE 1.—Effect on B.O.D. of chlorination at various doses; experiment No. 21.

these depressions. Five drops of distilled water were placed in the second and fourth to provide equal dilution of the dye. Sulfite concentrations of 2 p.p.m. caused perceptible fading within 3 min.

6. In any case where excess sulfite was detected by this procedure, additional volumes of the chlorinated sewage reserve were introduced into the stirring vessel until both ortho-tolidine and malachite green tests were negative.

All chlorine solutions used in this work were prepared in 1-l. graduates by diffusing chlorine gas from a laboratory cylinder through a carborundum diffuser bulb. Solutions were made up of a strength of approximately 2,500 p.p.m. and were stored in stoppered bottles shielded with black paper and kept under refrigeration. No chlorine solution was used after it was more than a month old. All sewage used was fresh raw sewage from the combined sewer serving a residential area in Cambridge, Mass., and had a chlorine demand of about 4 p.p.m. All dilution and incubation procedures and the dissolved oxygen determinations followed "Standard Methods" (14) practice.

Variation of B.O.D. Reduction with Increasing Chlorine Doses

To determine the range of B.O.D. reductions effected by increasing chlorine concentrations, portions of a batch of sewage were chlorinated with geometrically increasing doses of 3.2 p.p.m., 10 p.p.m., 32 p.p.m., 100 p.p.m., and 317 p.p.m., the latter value being well above the chlorine concentration required to produce a "break point" in the raw sewage. A 30-min. contact period was allowed before dechlorination and dilution for incubation. Quadruplicate D.O. determinations were made daily. The results are shown in Figure 1.

The unimolecular parameters of each of the six series have been calculated by the "two-moment method" (9). The daily ordinates of each series have been calculated from these parameters and plotted as the lines of best fit for the respective series of data.

The k values decline in an irregular series from 0.24 for the control to 0.13 for the highest chlorine concentration. Likewise, the L values are progressively reduced from 121 p.p.m. to 87 p.p.m., the percentage reduction being 10.3, 20.6, 26.7, 35.4, and 42.2, respectively, for the increasing chlorine doses. The parameter $k\,L$, which is the initial change of B.O.D. per unit time, is also shown for each series. The absence of any detectable lag period in any of the series indicates the completeness with which the dechlorination was carried out. Here, in agreement with the findings of earlier workers, the incremental reductions are greatest for chlorine doses sufficient to satisfy the chlorine demand. Above that concentration the additional B.O.D. reductions are not commensurate with the quantities of chlorine required to effect them.

B.O.D. Reduction by Chlorination of Pre-Incubated Sewage Dilutions

It was suggested to the author that it should be possible to express the B.O.D. reduction effected by chlorination in terms of the time of incubation at 20° C. required to effect the same reduction. To test this suggestion, a series of experiments (Nos. 10, 13, 15, 19, and 20) was run according to the following procedure:

1. A large volume of 3 per cent sewage dilution was prepared.

2. A portion of this was chlorinated for a period of 2 hr., dechlorinated, reseeded with 0.1 per cent of stale settled sewage, bottled, and incubated. These bottles were designated Series B in each experiment; namely, that series which had received no incubation before chlorination.

3. The remainder of the diluted sample was also bottled and incubated. Two of these bottles were withdrawn each day for D.O. determination, thus constituting a control series designated as Series A.

4. After varying periods of incubation, batches of bottles were withdrawn from the incubator and their contents pooled in a large jug. This pooled sample was chlorinated, dechlorinated, re-seeded, and re-bottled for continued incubation in exactly the same manner as Series B. These series were designated Series C, D, etc., to denote one-day pre-incubation, two-day pre-incubation, etc.

5. D.O. determinations on duplicate samples of each series were made each day.

6. To the B.O.D. observed on any day of Series C, D, etc., was added the B.O.D. exerted during the respective pre-incubation interval as shown by Series A. The total represents the cumulative B.O.D. satisfied before and after chlorination.

The dose of chlorine applied to the diluted sewage was 2.25 p.p.m. and a 2-hr. contact period was allowed. For experiment No. 15, in which the chlorine concentration was determined by photometrically evaluated ortho-tolidine tests before dechlorination, the results given in Table I were recorded. Thus, it was clear that the chlorine concentration chosen was great enough to satisfy the chlorine demand of the 3 per cent dilution.

Figure 2 presents the results of a typical run of this type. The progress of the B.O.D. reaction in the unchlorinated control (Series A) is shown by the solid line passing through the open circles. The solid line passing

TABLE I.—Residual Chlorine, Experiment No. 15

Series	Residual Chlorine (p.p.m.)	Contact Period
B	1.5	2 hr.
D	1.8	2 hr.
E	2.0	15 min.
	1.8	2 hr.
F	2.0	15 min.
	1.9	2 hr.
G	2.0	15 min.
	1.9	2 hr.

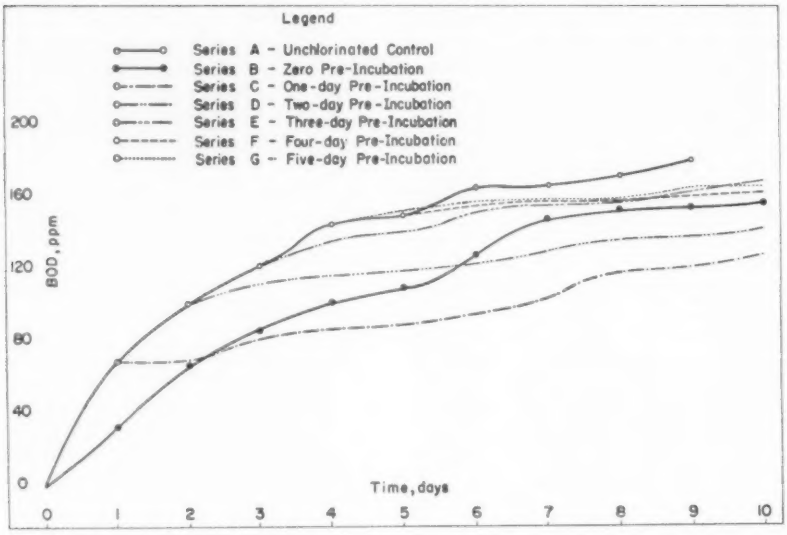

FIGURE 2.—Effect on B.O.D. of pre-incubation followed by chlorination; experiment No. 13.

through the dark circles charts the progress of the biochemical oxidation in the portion of the dilution that was chlorinated with no pre-incubation (Series B).

Each of the broken lines shows the course of the B.O.D. reaction in one of the pre-incubated series. For example, the lowest represents Series C; namely, the series that was incubated for one day prior to chlorination. The ordinate height under each of these broken lines represents the sum of the B.O.D. executed during pre-incubation plus the B.O.D. exerted during the incubation period following chlorination.

It is apparent that no direct comparison is possible between the amount of B.O.D. satisfied by incubation and the amount removed by chlorination. The amount satisfied by incubation is a single ordinate; namely, the difference in B.O.D. at the beginning and end of a stated incubation interval. By contrast, the amount of B.O.D. removed by chlorination is a series of ordinate differences between two approximately unimolecular curves having different reaction velocity constants and different limiting values. Thus, a comparison of the data of these experiments had to be made on a relative basis.

The parameters used for this comparison are shown in the insert on Figure 3. The ordinate y represents the B.O.D. exerted during the pre-incubation period of any series. The ordinate L, as usual, is the ultimate first-stage B.O.D. The ratio y/L expressed as a percentage, indicates the proportion of the first-stage B.O.D. satisfied during the pre-incubation period. This pre-incubation parameter is plotted as the abscissa in Figure 3. The ordinate difference r represents the difference in B.O.D. between the pre-incubated chlorinated sample and the unchlorinated control five days following chlorination and is, therefore, a measure of the effect of chlorination in reducing the B.O.D. The ratio r/L expressed as a percentage expresses

the proportion of the ultimate first-stage B.O.D. that was removed by chlorination. This chlorination effectiveness parameter is plotted as the ordinate in Figure 3.

The trend of the points in Figure 3 is the correlation between these two parameters. It is apparent that there is an optimum intermediate stage in the aerobic decomposition of sewage at which the application of chlorine yields a maximum reduction in the B.O.D. subsequently exerted. This optimum appears to have occurred when approximately 40 per cent of the B.O.D. had been satisfied.

Chlorination Following Anaerobic Incubation

The implications of these results suggest three questions for which answers were sought. First, does a similar optimum occur at some intermediate stage of an anaerobic decomposition? Second, is there a method of treating sewage in its undiluted state that will effect rapid decomposition to a state where chlorination will yield optimum B.O.D. reductions? The third question stems from the fact that it has been shown that B.O.D. is exerted more slowly in chlorinated than in unchlorinated sewage and may be phrased thus: does it follow that a pre-chlorinated sewage is thereby rendered more difficult to treat subsequently by biological methods?

TABLE II.—Chlorine Demand of Sewage During Anaerobic Decomposition

Period of Incubation (days)	Chlorine Demand (p.p.m.)
Initial	4.4
1	4.4
2	7.0
3	14.5
4	20.0
5	31.0

To gain a preliminary answer to the first question, a 9-l. sample of cotton-filtered sewage was allowed to incubate anaerobically at 20° C. under an atmosphere of nitrogen for five days. Daily

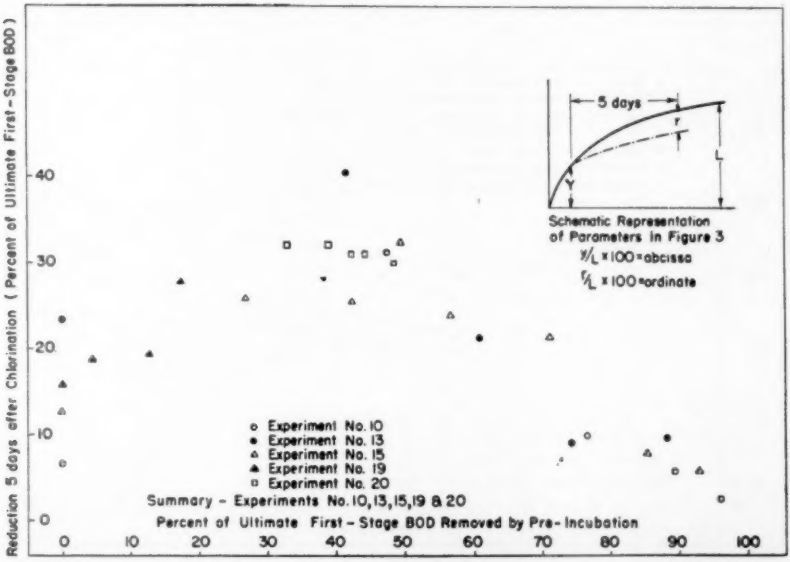

FIGURE 3.—Effect on B.O.D. reduction of pre-incubation prior to chlorination; summary of experiments No. 10, 13, 15, 19, and 20.

TABLE III.—B.O.D. Parameters for Anaerobically Decomposing Sewages

Series	Incubation Period (days)	k	L	kL
A	0	0.285	153	43.6
C	1	0.285	144	41.0
E	2	0.310	106	32.9
G	3	0.331	95	31.4

samples were drawn for experimentation, the liquid volume being replaced by nitrogen to maintain the anaerobic conditions. The chlorine demand of each day's sample was determined (Table II). From each daily sample, a 3 per cent dilution was prepared and bottled for incubation as the unchlorinated control. Sufficient bottles were incubated to permit duplicate daily D.O. determinations for each series through the 10th day of the experiment. A portion of each day's sample was chlorinated to a concentration of 4 p.p.m. This satisfied the chlorine demand of the original sewage, but as a demand increased with incubation, the constant dose of 4 p.p.m. represented less than 100 per cent satisfaction of the chlorine demand. The B.O.D. decreased during the incubation period and the uniform chlorine dose served as the constant factor relating these two variables.

The series were identified as follows:

Series	Description
A	Original sample
B	Original sample chlorinated
C	One-day anaerobic incubation
D	One-day anaerobic incubation plus chlorination
E	Two-day anaerobic incubation
F	Two-day anaerobic incubation plus chlorination
G	Three-day anaerobic incubation
H	Three-day anaerobic incubation plus chlorination

The resulting data have been plotted in three ways to facilitate comparison of the various series. In Figure 4, all eight series are shown on a single plot with the origin of each pair (chlorinated sample and unchlorinated con-

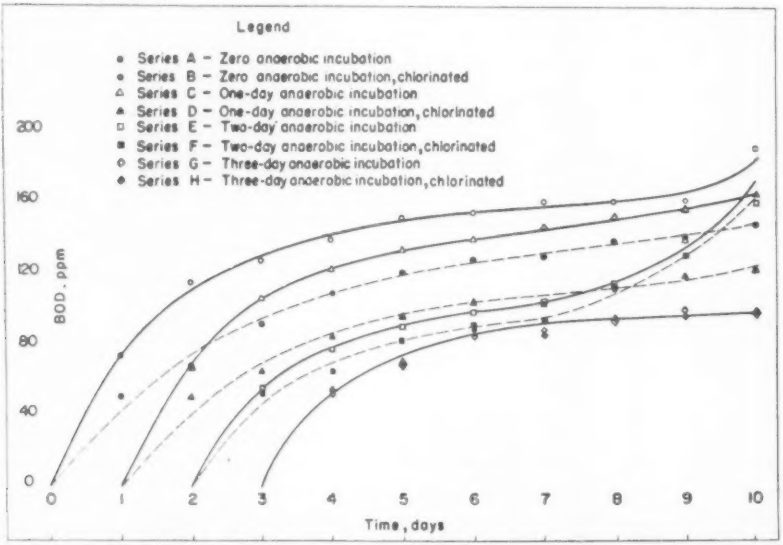

FIGURE 4.—Effect on B.O.D. of anaerobic incubation and chlorination; experiment No. 17.

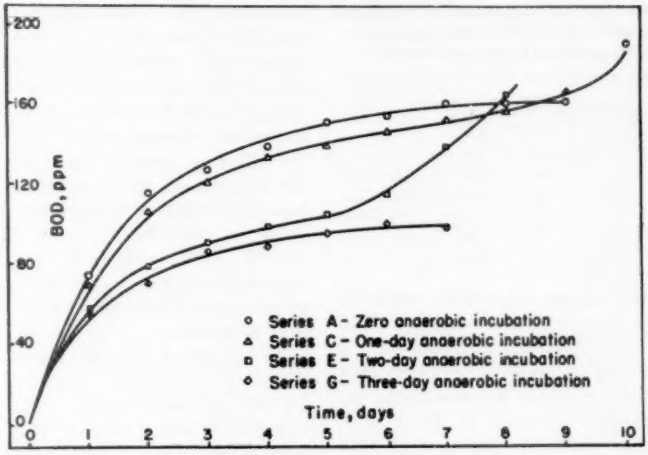

FIGURE 5.—Effect on B.O.D. of anaerobic incubation; unchlorinated controls, experiment No. 14.

trol) separated from one another by one day, corresponding to the one-day interval of anaerobic incubation by which each pair differs from the next. In Figure 5, all the unchlorinated controls have been superimposed from a common origin to facilitate a comparison of the rates of B.O.D. exertion and the successive reductions of the ultimate first-stage B.O.D. A summary of the parameters for these four series is given in Table III. In Figure 6, the four chlorinated series have been superimposed from a common origin. A summary of the B.O.D. parameters in these series is given in Table IV.

In this experiment, the chlorine dose was so chosen that no residual chlorine remained at the end of 15 min. Thus, the 4.0 p.p.m. of chlorine applied in each of the series of chlorinated samples was "absorbed." The

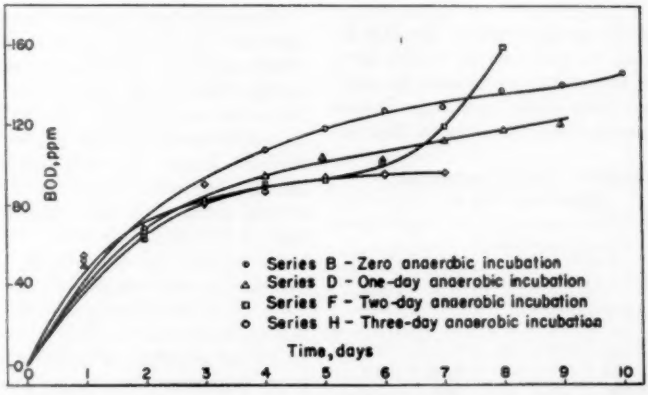

FIGURE 6.—Effect on B.O.D. of anaerobic incubation; chlorinated controls, experiment No. 14.

TABLE IV.—B.O.D. Parameters of Chlorinated Sewage after Varying Periods of Anaerobic Decomposition; Experiment No. 14

Series	Incubation Period (days)	Satisfaction of Chlorine Demand %	k	L	kL
B	0	91.0	0.174	136	23.7
D	1	91.0	0.230	110	25.3
E	2	57.2	0.301	96	28.9
H	3	27.6	0.354	95	33.6

parts per million of B.O.D. removed per part per million of chlorine "absorbed" are recorded in Table V.

From this summary, it appears that the character of the sewage again exerts a greater influence on the B.O.D. reduction observed than does the amount of chlorine used. For the fresh sewage and for the sample taken after one day of anaerobic incubation the p.p.m. of B.O.D. removed per p.p.m. of chlorine "absorbed" was much greater than the value of 2 proposed by Mohlman, Hurwitz, and Ruchhoft (8). It follows that any of the criteria suggested thus far to express the amount of percentage of B.O.D. reduction associated with chlorination can only be an approximate measure of accomplishment in the absence of information that will reflect the conditions of the materials in sewage.

What the magnitude of the B.O.D. reductions in each series would have been if the chlorine demand in each case had been fully satisfied, cannot be answered from the data of this experiment. It is clear that they could not have amounted to as much as 8.5 p.p.m. per p.p.m. of chlorine "absorbed" in every series. For this ratio to have held for Series H (three-day anaerobic decomposition), in which the chlorine demand was 14.5 p.p.m., the application and absorption of 14.5 p.p.m. of chlorine would have brought about a reduction of 128 p.p.m. of B.O.D. Such a reduction was patently impossible, as the 5-day B.O.D. of the unchlorinated sewage on that day was only 95 p.p.m.

TABLE V.—B.O.D. Reductions; Experiment No. 14

Incubation Period (days)	Ultimate First-Stage B.O.D. (p.p.m.)			B.O.D. Reduction (%)	B.O.D. Reduction per P.P.M. Chlorine (p.p.m.)
	Control	Sample	Reduction		
0	153	136	17	11.1	4.2
1	144	110	34	23.6	8.5
2	106	96	10	10.4	2.5
3	95	95	0	0.0	0.0

As compared with the optimum condition for chlorine application observed in aerobically pre-incubated samples, it seems fair to state that a similar optimum occurs in anaerobically decomposing sewage. This optimum corresponds to the condition of a sample of sewage that has decomposed anaerobically for a period of 24 hr. The increased efficiency of chlorination obtained thereby is quickly lost by continuing anaerobic decomposition, because the chlorine demand of the material increases rapidly and a considerable fraction of the chlorine applied reacts in such a way as to yield minimal B.O.D. reductions.

Chlorination Following Plain Aeration

Plain aeration was next tried to determine whether an aerobic decomposition could be promoted in undiluted sewage that would bring about a similar optimum moment for chlorination as was observed in the pre-incubation series. Mann (6) and others have shown that plain aeration of raw or settled sewage brings about a reduction of B.O.D.; after about 8 hr., further reductions of B.O.D. require excessively prolonged periods of aeration. For the purposes of this study, it appeared that the desired reduction in B.O.D. might be effected in less than 2 hr. Therefore, two experiments were run to determine what B.O.D. reductions follow chlorination of sewages

that have been previously aerated for varying periods of time. Each experiment was subdivided into 10 series as follows:

Series	Description
A	Original sample; control
B	Original sample, chlorinated
C	30-min. plain aeration
D	30-min. plain aeration, chlorinated
E	60-min. plain aeration
F	60-min. plain aeration, chlorinated
G	90-min. plain aeration
H	90-min. plain aeration, chlorinated
I	120-min. plain aeration
J	120-min. plain aeration, chlorinated

The course of B.O.D. exertion for sewage treated by plain aeration has not been described in the literature. Hence, there was no basis for judging whether the observed B.O.D. reductions were due to a decrease in k, a decrease in L, or a decrease in both. For that reason, Series A, C, E, G, and I were prepared in sufficient quantity to permit quadruplicate daily D.O. determinations at daily intervals for 5 days. Inasmuch as the course of the B.O.D. reaction in chlorinated samples had already been traced repeatedly, the dilutions of Series B, D, F, H, and J were prepared for quadruplicate D.O. determinations on the fifth day only. A constant chlorine dose of 5 p.p.m. with a 30-min. contact period was used for each of the chlorinated series. This dose was great enough to produce a slight 30-min. residual, which was removed by the dechlorination procedure previously described. Typical results of these experiments are shown in Figure 7. The smooth curves are calculated curves of best fit for the plain aeration series (open symbols). The dark symbols at the fifth day show the B.O.D. of the chlorinated member of each pair of series. The unimolecular parameters for the exertion of B.O.D. in sewage subjected to plain aeration are shown in Table VI.

To express the results of these experiments in terms of parameters comparable to those used in the pre-incubation experiments, the aeration effectiveness parameter used is the ratio of the reduction of ultimate first-stage B.O.D. effected by aeration to the ultimate first-stage B.O.D. of the original sewage expressed as a percentage; that is, $\frac{L - L_i}{L} \times 100$. The chlorination effectiveness parameter is the ratio of reduction of 5-day B.O.D. effected by chlorination to the ultimate first-stage B.O.D. of each control expressed as a percentage, $r/L_i \times 100$. The values of these parameters are tabulated in Table VII. At the optimum, B.O.D. reduction by plain aeration followed by chlorination amounted to approximately 40 per cent.

On the basis of these limited experimental data, the combination of sedimentation, 1-hr. plain aeration, and

TABLE VI.—Parameters of B.O.D. Exertion in Sewage Subjected to Plain Aeration

Experiment Number	Parameter	Period of Aeration (min.)				
		0	30	60	90	120
17	k	0.223	0.223	0.220	0.216	0.185
	L	206	164	154	158	154
	kL	45.9	38.2	33.8	34.1	28.5
18	k	0.250	0.237	0.230	0.225	0.212
	L	222	177	170	166	166
	kL	55.5	41.9	39.1	37.2	35.2

TABLE VII.—Plain Aeration and Chlorination Parameters; Experiments No. 17 and 18

Experiment Number	$\frac{L - L_i}{L} \times 100$	$r/L_i \times 100$
17	0	12.9
	20.4	18.9
	25.2	11.8
	23.2	12.3
	25.2	14.6
18	0	14.6
	20.3	17.9
	23.4	20.6
	25.2	10.2
	25.2	1.3

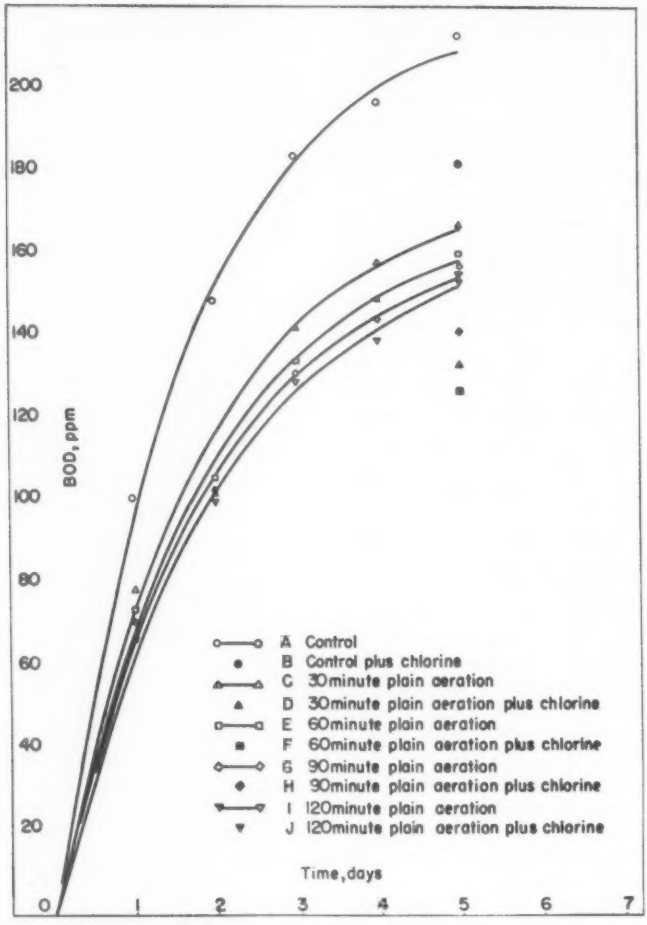

FIGURE 7.—Effect on B.O.D. of aeration and chlorination; experiment No. 18.

chlorination seems to offer possibilities for an intermediate degree of sewage treatment. Such a combination would possess an advantage which should not be overlooked; namely, that the volume of solids to be handled from such a treatment process would be no greater than that associated with sedimentation alone.

The degree of sewage treatment that might be expected to result from such a combination can be approximated by

$$\text{Plant efficiency} = p_1 + p_2 - p_1 p_2$$

in which p_1 is the fraction of the 5-day B.O.D. removed by sedimentation, and p_2 is the fraction removed from the settled sewage by plain aeration and subsequent chlorination. On the basis of 35 per cent removal by sedimentation and 40 per cent B.O.D. removal by 1-hr. aeration and chlorination, the

over-all plant efficiency would be 61 per cent. Demonstration on a plant scale will be required before it can be shown whether these indications of the effectiveness of combined aeration and chlorination can be equaled or improved in practice.

Biological Treatment of Chlorinated Sewage

The results of the investigation up to this point had shown repeatedly that the B.O.D. reaction velocity constant, k, for chlorinated sewage was consistently lower than the same parameter for unchlorinated controls. The inference is that the biochemical oxidation of chlorinated sewage by such biological processes as trickling filtration or activated sludge may be less efficient than the biochemical oxidation secured on unchlorinated sewage with the same processes. Indeed, the literature contains some evidence to substantiate the inference. Harlow and Powers (4) have reported that chlorinated phenolic wastes could not be properly treated on trickling filters and had to be separated from other phenolic wastes for special treatment. Rudolfs and Lacy (11) found that the removal of B.O.D. by activated sludge aerated with chlorinated sewage was less than that secured with unchlorinated sewage. They also reported that this diminution of the efficiency of B.O.D. removal became more marked as the chlorine demand of the sewage was more nearly satisfied.

The extent of this diminution may depend on the degree to which the removal of B.O.D. by biological treatment is effected by immediate biochemical oxidation of organic substances or by their separation from the liquid by physical forces such as adsorption and entrainment. These removal mechanisms are not mutually exclusive, and observed reductions are due to simultaneous action of a complexity of physical and biological forces. Because physical forces will probably exhibit little or no selectivity between chlorinated and unchlorinated materials, a primarily physical process should show little or no difference in the amounts of B.O.D. removed from control and sample. By contrast, a primarily biochemical process may act much more slowly on sewage constituents that are already partially stabilized by chlorine.

An exploratory experiment (No. 22) was set up in the following manner:

1. Activated sludge was cultivated in the laboratory for a period of two weeks. The sludge was settled, decanted, and fed twice daily with fresh cotton-filtered Oxford Street sewage.

2. On the day of the experiment, the sludge was decanted and washed three times with tap water to free it of unassimilated materials.

3. The washed sludge was separated into three equal volumes by dipping it with a 25-ml. porcelain casserole from a large shallow dish and pouring the casserole contents, successively, into each of three 250-ml. graduate cylinders. The total, fixed, and volatile solids were determined on one portion, the other two being added, respectively, to the control and the sample in 2,000-ml. beakers.

4. The chlorine demand of fresh, cotton-filtered sewage was found to be 3 p.p.m. Six liters were dosed with 5 p.p.m. of chlorine, allowed to stand for 30 min., and dechlorinated.

5. Simultaneously, 1,750 ml. of this chlorinated sample and an equal volume of the unchlorinated control were poured into 2,000-ml. beakers and the sludge added as indicated in step 3 above.

6. Both beakers were placed under the jar-test stirring mechanism and the paddle speed was adjusted until the velocity and turbulence of the liquid were just sufficient to keep all sludge particles in motion. No aeration was provided during the contact period. After 30 min., both beakers were

TABLE VIII.—Parameters of B.O.D. Exertion by Activated Sludge Effluents of Chlorinated and Unchlorinated Sewage

Series	Description	k	L	kL
A	Control	0.226	90	20.3
B	Chlorinated sample	0.178	83	14.8
C	Sludge-treated control	0.168	40	6.7
D	Sludge-treated chlorinated sample	0.193	47	9.1

removed, the mixture was allowed to settle for 5 min., and the supernatants were filtered through washed filter paper.

7. The first 240 ml. of filtrate were diluted to 8 l. (3 per cent) with seeded dilution water and bottled for incubation. Quadruplicate bottles were withdrawn for D.O. determinations at daily intervals.

8. Similarly filtered portions of the control and chlorinated sample were prepared for incubation in a like manner.

The results of this experiment are presented graphically in Figure 8 and the calculated k and L values are listed in Table VIII.

The total solids contents of a 250-ml. batch of the original activated sludge was 9,286 p.p.m., of which 7,709 p.p.m. (83 per cent) were volatile. Upon dilution in 1,750 ml. of control or sample, the resultant concentration was 964 p.p.m. of volatile solids. During the 30-min. contact period the unit B.O.D. removal from the control was 0.046 g. per gram of volatile solids, as compared with a value of 0.037 from the chlorinated sample.

Under the conditions of this experi-

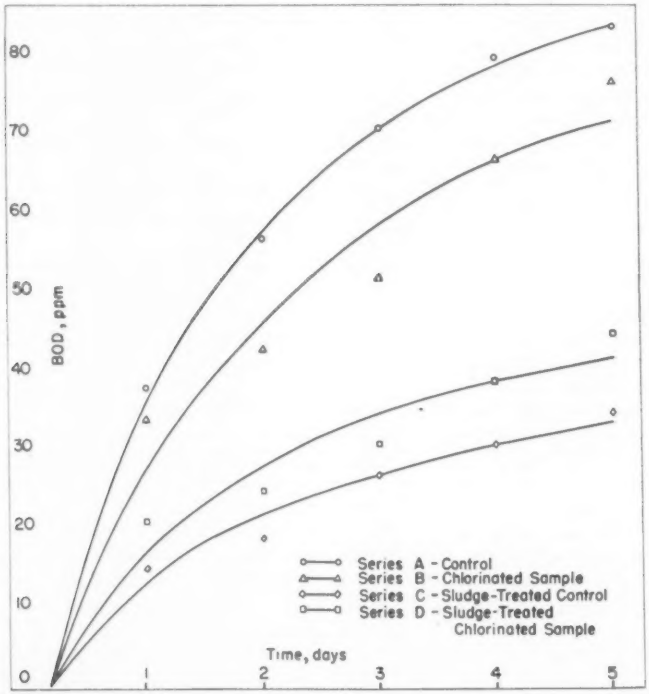

FIGURE 8.—Effect on B.O.D. of seeding and chlorination; experiment No. 22.

ment, these results indicate that the removal of B.O.D. by activated sludge from chlorinated sewage is less complete than that from unchlorinated sewage. It was necessary to use a short contact period without aeration in order to leave sufficient B.O.D. in the effluents to permit calculation of the values of k and L. Without aeration, the oxygen-utilizing processes of the sludge organisms were limited to the amount of dissolved oxygen present in the sewage. Such a condition, by limiting the extent of biochemical oxidation, favored B.O.D. removal by physical processes. In spite of this, the results indicate, insofar as a single experiment can do so, that there was a distinct reduction in the amount of B.O.D. which activated sludge could remove from chlorinated sewage in a stated period of time as compared with the amount removed from unchlorinated sewage.

Conclusions

Although the experimental data of this work are too few to warrant definitive conclusions, the following points previously unreported in the literature may be noted:

1. Dechlorination of chlorinated sewage sample with crystalline sodium sulfite can be done with such precision that subsequent exertion of B.O.D. in incubated dilutions shows no measurable lag phase due to chlorine toxicity to the seeding organisms and shows no measurable chemical oxygen demand due to excess sulfite.

2. There are both qualitative and quantitative changes in decomposable materials in sewage as a result of chlorination, as demonstrable by the reduction of the unimolecular parameters k and L. These reductions are progressive with increasing concentrations of applied chlorine, the greatest reduction increment resulting from applied chlorine dose sufficient to produce a slight 15-min. residual.

3. There is a stage in the decomposition of sewage, whether by aerobic or anaerobic organisms, that is optimum for the application of chlorine for B.O.D. reduction. This stage corresponds to 40 per cent exertion of the ultimate first-stage B.O.D. under dilute aerobic conditions. A similar optimum stage may be produced by periods of plain aeration in the undiluted stage of from 30- to 60-min. duration. Under conditions of anaerobic decomposition in the undiluted state, this optimum occurred at 35 per cent reduction of the ultimate first-stage B.O.D.

4. Anaerobic decomposition of sewage for periods up to 72 hr. effects a progressive reduction in the ultimate first-stage B.O.D. of the sewage, but the reaction velocity constant of the remaining B.O.D. is progressively higher than that of the original sample.

5. Due to the changing state of the organic materials in sewage, the amount of B.O.D. removed by chlorination is not linearly related to the amount of chlorine "absorbed." Specification of 2 p.p.m. B.O.D. removed per p.p.m. of chlorine "absorbed," or any similar criteria, represents, at best, a summary of average experience.

6. Plain aeration of sewage for intervals up to 2 hr. effects a reduction of the ultimate first-stage B.O.D. The reduction velocity constant of the B.O.D. remaining appears to be slightly reduced.

Acknowledgment

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PUBLIC WORKS AND MUNICIPAL SERVICES CONGRESS

The Biennial Public Works and Municipal Services Congress and Exhibition is scheduled to be held this year at Olympia, London, England, on November 3–8, 1952. This function is claimed to be the most comprehensive meeting place of administrative, executive, and technical functionaries of local government. It provides administrators and technicians a national forum of expert opinion on many problems with which public authorities are concerned at all times, and according to the sponsors may well be considered as the international clearinghouse for the interchange of ideas and improvements to aid those whose job is to administer and serve communal interests. The Exhibition, held in conjunction with the Congress, is expected to be the largest and most representative of its kind ever assembled under one roof.

Actually, the Congress and Exhibition is a merger of two events, previously held in alternate years, dealing with public works, roads, and transport and with public health and municipal services. Attendance is anticipated to include delegates from all over the world.

Further details about the Congress and Exhibition may be obtained from the Municipal Agency, Ltd., 68 Victoria St., London, S.W. 1, England.

TEMPERATURE EFFECTS ON TRICKLING FILTERS*

By G. J. Schroepfer, M. B. Al-Hakim, H. F. Seidel, and N. R. Ziemke

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The use of trickling filters in sewage treatment has increased steadily since their introduction in England in 1894. In 1945, for example, 1,581 of 2,897 plants in the United States then providing intermediate and secondary treatment used this process.

The efficiency of a trickling filter in removing biochemical oxygen demand from the sewage passing through it usually ranges from 20 to 80 per cent of the load applied to the filter. Filter efficiency is affected by many factors, among which are:

1. Load applied, volumetric and organic.
2. Characteristics of media.
3. Depth of filter.
4. Sedimentation provided, primary and secondary.
5. Character of the sewage applied.
6. Ventilation.
7. Temperature.

Becoming interested in the effect of temperature alone on filter efficiency, the authors began a systematic search of the literature for data and discussions which would contribute to an understanding of this problem. Requests for annual reports were sent to nearly 150 superintendents of trickling filter plants. Of this number, approximately one-fourth replied. Statistical studies were then made of actual plant operating results in an effort to evaluate numerically the effect of temperature variations.

This paper comprises a general discussion of temperature effects on the biological life within a filter, followed by an analysis of temperature effects on plant operating results.

Because of its close relationship to the problem of seasonal variations in filter performanace, a study was also made of natural ventilation in trickling filters. The results of this study have been reported by Johnson (5).

Temperature Effects on Biological Activity

General

It is generally agreed that the efficiency of the trickling filter process to reduce the biochemical oxygen demand of the sewage applied to it is dependent, at least partially, on reactions initiated and maintained by the biological life forms inhabiting the filter slime. Thus, in attempting to evaluate the effect of temperature on trickling filter efficiency, it seems appropriate to review some of the more recent knowledge concerning these biological organisms, especially as they are affected by changes in temperature.

Several excellent studies available in the literature have attempted to isolate and classify the various life forms associated with the trickling filter process. Loosely, the organisms might be classified into five rather broad groups —bacteria, fungi, protozoa, worms, and insect larvae—each represented by many different species and genera. The very complex nature of this society of organisms indicates that the removal of B.O.D. by trickling filters is a complicated series of actions and reactions not readily traced or easily understood. Also, this biological system is not fixed, but is constantly changing in response to many environ-

mental factors. Some of the organisms are in competition with each other for the available food supply contained in the sewage. Others are dependent for food on products produced by other organisms; still others get their food by ingesting other dead and living organisms.

In addition to this interrelation between different species, the entire mass of living organisms is subjected to an ever-changing set of environmental conditions, such as temperature and characteristics of the food supply. Thus, if one species is affected by a change in its environment, then other organisms in competition with this species or dependent on it for their food supply are also affected and the whole biological balance is adjusted to fit the new conditions. To attempt to evaluate the effect of changes in only one of these factors, such as temperature, in terms of the specific changes in the incidence and activity of each individual species, is probably an impossibility. However, several studies have reported some interesting general effects of variations in temperature on several of the more important life forms associated with the trickling filter process. A brief discussion of some of these observations might facilitate a better understanding of the effect of seasonal changes in temperature on the ability of the trickling filter process to remove B.O.D.

Effect of Temperature on Bacteria

Although it is recognized that the actions involved in the trickling filter process cannot be attributed entirely to any one specific organism, it is generally felt that the most important and most active group of organisms is bacteria. Studies by Butterfield *et al.* (1) isolated one of the most dominant species of bacteria found in filter beds, the slime-producing zoogleal bacteria. Experimental studies with pure cultures of this organism have indicated quite definitely that this species is the one to which most of the action of a trickling filter can be attributed. On the other hand, these studies also showed that pure culture zoogleal bacteria were not as efficient in the trickling filter process as a more complex biological flora and fauna. Accordingly, it appears that the removal of B.O.D. by trickling filters is a reaction which is largely initiated and maintained by zoogleal bacteria, but one which is improved somewhat by the presence of other competitive and dependent life forms.

If this is true, it becomes evident that the changes in the efficiency of the trickling filter to remove B.O.D. under varying temperature conditions should be largely traceable to the changes in the incidence and activity of the zoogleal bacteria. To the authors' knowledge there has been no work or study directly aimed at determining the effect of temperature on the bacteria in a filter. Concerning the numbers of bacteria, Butterfield has reported as many as 300,000,000 per c.c. of filter slime in one case. Also, Heukelekian (2) has reported varying quantities of slime in a filter under summer and winter temperatures, which indicates that the population of zoogleal bacteria varies with temperature. No direct measure of the bacterial activity in a filter under varying temperature conditions has been made. It is common knowledge among bacteriologists, however, that the activity or metabolic rate and rate of reproduction of most bacteria is speeded up by increased temperature. In the limited range of temperatures found in sewage, this increased activity has been reported to be as much as 1.5 to 2 times for an increase of 10° C. This is in line with knowledge of the rate of satisfaction of the first-stage biochemical oxygen demand at various temperatures. For instance, using the Phelps (3) formulation for computing the first-stage biochemical oxidation rate, it is found that if 51.5

p.p.m. of B.O.D. is satisfied in one day at 10° C., 100 p.p.m. will be satisfied in one day at 20° C. Inasmuch as the removal of B.O.D. by the filter alone is generally agreed to be a process of aerobic biochemical oxidation carried on principally by the zoogleal bacteria, it becomes apparent that the temperature of the bed is one of the major factors affecting the efficiency of the filter.

Effect of Temperature on Other Organisms

The incidence of the other groups of organisms inhabiting the filter slime have been found to vary during different seasons of the year. This is undoubtedly largely due to seasonal changes in temperature and adjustment of the biological balance to fit new temperature conditions. Although these organisms probably oxidize and stabilize some organic material, it is felt that their place in the trickling filter process is restricted to a supporting role. In general, the presence of limited numbers of fungi, protozoa, worms, and insect larvae in the filter slime is beneficial to the process. This is probably true only insofar as these organisms are beneficial to the bacterial population.

Most types of fungi and protozoa use the same food as bacteria and are, therefore, keen competitors for the available supply of organic material in the sewage. Under this competitive relationship fungi and protozoa would be expected to be more prevalent in filters during winter, when the bacterial level was at its lowest. Several investigators have actually found this to be true and have reported a higher number of fungi and protozoa in the filter slime during the winter months. The chief beneficial action of these groups is due to this competition, because they help to keep the bacterial population at its most active level. It has been demonstrated that if bacteria are allowed to grow and multiply without competition they soon reach a numerical limit, or ceiling value, after which their activity and reproduction are carried on at a much slower rate. Competitive organisms, especially the protozoans which ingest living bacteria, cause the bacteria population to work harder to keep their place in the filter.

The worm and larvae population of a filter has been found to reach a comparatively high level, especially during the warmer seasons of the year. These larger life forms undoubtedly consume and stabilize a certain amount of organic material, judging from the energy required for their unceasing action. Compared with bacteria, however, their numbers are almost insignificant and the benefit to the filter from this source is probably quite small. Their chief beneficial action has been attributed to their unceasing whip-like motion. They have commonly been referred to as "grazer" organisms, because they graze over and burrow through the slime and keep it loose and open to oxygen in the deeper layers. This provides oxygen to the hard-working bacteria, facilitates sloughing, and prevents clogging and ponding of the filter.

Importance of Evaluating Actual Temperature Effect

Considering this brief review of the effect of temperature on the activity of the biological life of a trickling filter, it became apparent to the authors that the temperature of the bed certainly should be one of the major factors affecting the efficiency of the process to remove B.O.D. Temperature has been mentioned by a number of past investigators as one of the factors affecting the efficiency of the trickling filter process. These reports have indicated the need for further study. To this end, the purpose of this investigation was to study and evaluate the effect of temperature on filter efficiencies from plant operating results.

Temperature Effects on Plant Operating Results

Problems Involved

A search of the literature revealed agreement on the commonly recognized fact that filter efficiencies were generally higher in warm weather than in winter. In an attempt to evaluate this trend or effect numerically, operating records of a number of treatment plants were studied quite carefully.

Sewage temperature *vs.* air temperature.—Granting that filter efficiency varies with temperature, the question immediately arose as to which temperature was significant, that of the air or that of the sewage. A review of published data indicated that the sewage temperature rarely drops more than 4° to 6° F. in passing through the filter bed, even under severest winter conditions. One of several tests made by the writers at the Excelsior, Minn., plant confirmed this by showing a 4° F. drop in sewage temperature coincident with a 52° F. rise in the temperature of the air passing through the filter. Results of these tests are summarized in Table I.

The weight of the sewage passing through a low-rate (3-m.g.a.d.) housed filter, even under very severe winter conditions, is likely to be at least 10 times that of the air flow. Under summer conditions, when air and sewage temperatures become nearly equal, this ratio could approach infinity. In view of this and the further fact that the specific heat of water is four times that of air, the heat content or transfer capacity of the sewage passing through a filter is many times that of the air moving through the rock bed. Although sewage temperature is affected by air temperature, it is felt that the temperature of the sewage is by far the best key to the actual filter bed temperature. This is particularly true for high-rate filters, in which the continuous dosing keeps the temperature of the slime very near the sewage temperature. In low-rate filters, on the other hand, the rest periods between dosing cycles undoubtedly permit the average slime temperature to differ somewhat from the sewage temperature, depending on the length of the rest period and on the temperature of the air moving through the filter bed. Except for thaws and rains, sewage temperature does not often vary more than 5° F. over a 24-hr. period, and its annual variation usually does not exceed 20° or 25° F. Therefore, the variation in filter efficiency due to temperature change is also likely to be limited.

TABLE I.—Typical Temperature Data for Excelsior, Minn., Trickling Filter

Date (1949)	Air Temp. (°F.)		Sewage Temp. (°F.)	
	Outside	Inside Building	On Filter	Leaving Filter
Jan. 22	−12	40	50	46
Feb. 5	12	41	48	46
Jan. 15	36	42	50	49.5

Illustrated in Figure 1 are seasonal variations in air and sewage temperatures at the Akron, Ohio, plant over a two-year period. Also plotted is the filter efficiency, the pattern of which follows the fluctuation of sewage temperature rather closely. The degree of variation of the two patterns is also quite similar.

Obtaining usable data.—In evaluating plant records for this purpose, it was necessary to know:

1. The B.O.D. load on the filter.
2. The B.O.D. removal by the filter and settling tank.
3. The temperature of the sewage.

The determination of filter loading and removal also implies an understanding of plant operating procedures, paramount among which are the method and amount of recirculation. Only five of the plant records examined were complete enough for analysis; the greatest lack was data on sew-

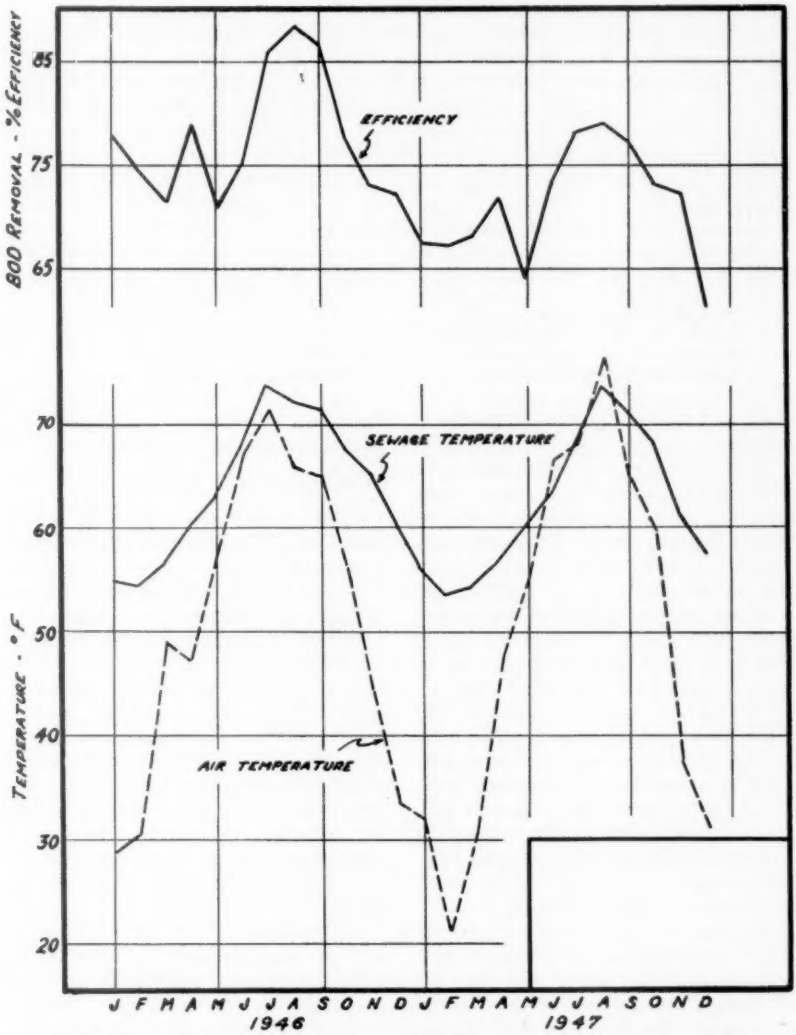


FIGURE 1.—Typical temperature and filter efficiency variations, Akron, Ohio.

age temperature. It was interesting to note that air temperatures are recorded in most plants, although sewage temperatures are not.

Statistical Methods

All statistical methods are based on the theory of sampling and on the assumption that all samples are of equal value. In this case, no control over the sampling was possible and monthly average plant operating results for filter loading, efficiency, and sewage temperature were used just as reported. No data were discarded except when the operator stated that

TABLE II.—Characteristics of Plants Investigated

Plant	Raw Sewage		Primary Settling Time (hr.)	Trickling Filter				Sec. Settling Time (hr.)
	B.O.D. (p.p.m.)	S.S. (p.p.m.)		Vol. (acre-ft.)	Depth (ft.)	Loading (m.g.a.d.)	Distr.	
Akron, Ohio	200	320	1.5	140	10	3.6	Int.	1.0
Decatur, Ill.	100[1]	—	2.6[2]	18	6	3.2– 3.3	Int.	0.5
Ft. Jackson, S. C.	300	250	3.4	2.0	5	17.4–18.3	Cont.	3.0[3]
Austin, Minn.:								
1st stage	600–800	400–450	2.3[4]	1.0	6	19.2–21.8	Cont.	1.5[5]
2nd stage	—	—	1.5[5]	6.6	7.5	3.5– 4.1	Int.	1.5
Baltimore, Md.	160[1]	—	2.0	12.7	8.5	3.0	Cont.	([6])

[1] Strength of sewage applied to filter.
[2] Preceded by 1.2 hr. pre-settling and 2.5 hr. pre-aeration.
[3] Dependent on recirculation method.
[4] Preceded by 35 min. flocculation.
[5] Intermediate settling tank.
[6] Study made of filter only.

the plant was upset or only partly in service.

If the temperature effect was to be evaluated successfully, it was necessary to minimize the effect of the B.O.D. loading on the filter efficiency. The effect of variations in B.O.D. loading on the efficiency of trickling filters has been well defined by others; it has been shown that filter efficiencies will be reduced somewhere between $\frac{1}{3}$ and 1 per cent for every 100 lb. of B.O.D. per acre-foot per day the filter loading is increased. The loading effect was reduced as far as possible by arranging the statistical studies of operating results in groups falling within a narrow loading range. It was then assumed that the load variation within each range had a negligible effect on filter efficiency.

For ease of comparison, data for all plants were plotted on coordinate systems of the same scale. For each set of data, a line of best fit (or line of regression) was then computed by the least squares method. It was assumed that, within the range of values studied, a straight-line (linear) line of regression, of the form $Y = m\ X + b$, best fitted the data available.

Also computed for each group of data was the coefficient of correlation, which is a measure of "association," or the success with which the line of best fit represents the individual points making up the group.

Individual Plant Results

Data on the five plants on which sufficient information for analysis were readily available are summarized in Table II. It was hoped at the start of this investigation to compile information from plants experiencing extremes in temperature variation. For lack of data, the study was limited to only 10° of latitude (from Austin, Minn., to Fort Jackson, S. C.) However, the five individual plants experienced quite wide sewage temperature variations during the period for which the data were studied. The lowest temperature range from summer to winter was 20° F. and the highest was 26° F.

Akron, Ohio.—The Akron plant is an open standard-rate trickling filter with Imhoff tanks serving as primary sedimentation units. After passing through bar racks, grit chambers, and fine screens, the sewage is settled and applied to the trickling filters by dosing siphons and a fixed-nozzle distribution system.

A statistical study was made of monthly average operating results for the period of 23 consecutive months from February, 1946, to December, 1947, inclusive. During this period,

the average raw sewage load on the plant was approximately 50 m.g.d., with a strength of roughly 200 p.p.m. 5-day B.O.D. and 320 p.p.m. suspended solids. The effect of sewage temperature variations on filter efficiency is shown in Figure 2. The trend of increasing efficiency with a rise in temperature is quite apparent; the equation of the line of regression for the efficiency of filter and sedimentation tank combined is $Y = 0.740X + 27.4$, indicating that a 1° F. temperature rise will result in an increase of 0.74 per cent in efficiency. In other words, according to the equation, an increase in sewage temperature from 60° F. to 70° F. will result in a 7.4 per cent efficiency increase, or from 71.8 to 79.2 per cent. In the above equation, the slope (0.740) in terms of per cent per °F. is the important factor; the Y-intercept (27.4) is merely an aid in defining the location of the line for the temperature range involved.

In the Akron plant, tests are also run on unsettled filter effluent, thus making it possible to evaluate the efficiency of B.O.D. removal by the filter alone. This data is also plotted on Figure 2; its line of regression has a flatter slope (0.520) than that for filter and settling combined. It is interesting to note that during the 23-month period, the average efficiency of the filter alone was 64 per cent and that of the filter and sedimentation tank combined was 75 per cent; of this combined removal, 85 per cent was thus accomplished by the filter alone.

Decatur, Ill.—Hatfield (4) describes the operation of the trickling filters at the Decatur sewage treatment plant, presents the relation between sewage temperature and filter efficiency variation, and discusses the importance of the temperature effect. The operating data presented by Hatfield are included as part of this study because of their basic worth.

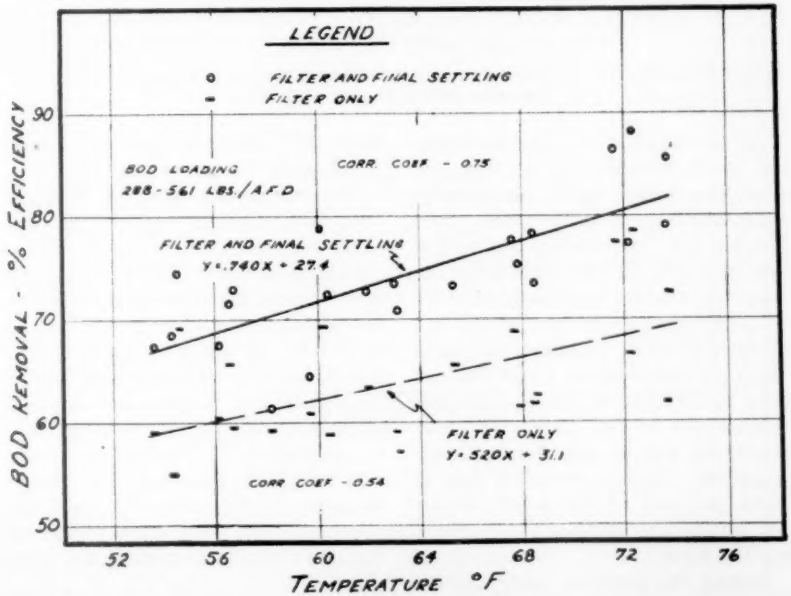


FIGURE 2.—Effect of temperature on filter efficiency; Akron, Ohio, standard-rate filter, 1946 and 1947.

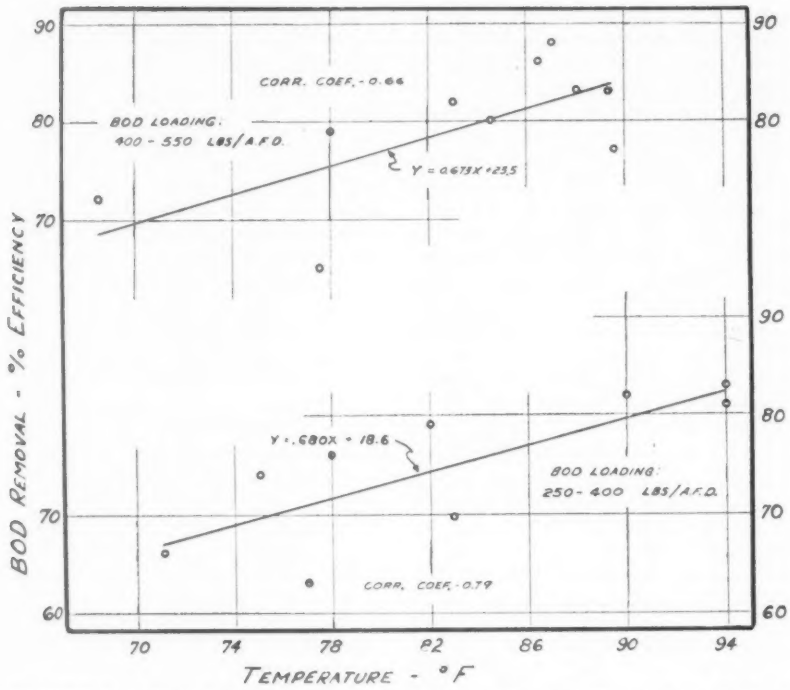


FIGURE 3.—Effect of temperature on filter efficiency; Decatur, Ill., standard-rate filter under two loading ranges, 1928–1930.

At the time of the original study, the plant included screens and grit chambers, Imhoff tanks for primary sedimentation, a pre-aeration stage followed by intermediate sedimentation, and open standard-rate filters followed in turn by final sedimentation. At an average sewage load of approximately 10 m.g.d., detention periods at that time were roughly 1.2 hr. for primary sedimentation, 2.5 hr. for pre-aeration, 2.6 hr. for intermediate sedimentation, and 30 min. for final sedimentation. It was estimated that 45 to 50 per cent of the B.O.D. of the raw sewage was removed before reaching the filters.

During the period of study, the average strength of the sewage delivered to the filter by the dosing siphons and fixed-nozzle distribution system was approximately 100 p.p.m. B.O.D.

For purposes of analysis, the data were first divided into two groups: those for which filter loading values ranged from 250 to 400 lb. B.O.D. per acre-foot per day, and those for which the loading ranged from 400 to 550 lb. B.O.D. per acre-foot per day. The trends for each load group are shown in Figure 3. Within such a small range, the filter loading seems to have a negligible effect; the slopes of the two lines of regression are nearly identical (0.680 and 0.673), and the positions of the two lines, if plotted on the same coordinate system, are quite similar.

Fort Jackson, S. C.—The Fort Jackson plant is a single-stage, recirculating,

high-rate filter plant designed to treat the wastes from a military camp. The major sewage treatment units are bar screens and grit chambers, two circular primary clarifiers, four trickling filters, and three circular secondary clarifiers. During the period of study the average raw sewage load on the plant was approximately 3 m.g.d., with a strength of approximately 300 p.p.m. B.O.D. and 250 p.p.m. suspended solids.

The plant piping is arranged to permit recirculation of either unsettled or settled filter effluent, or both, back to the filters. At times, a mixed effluent

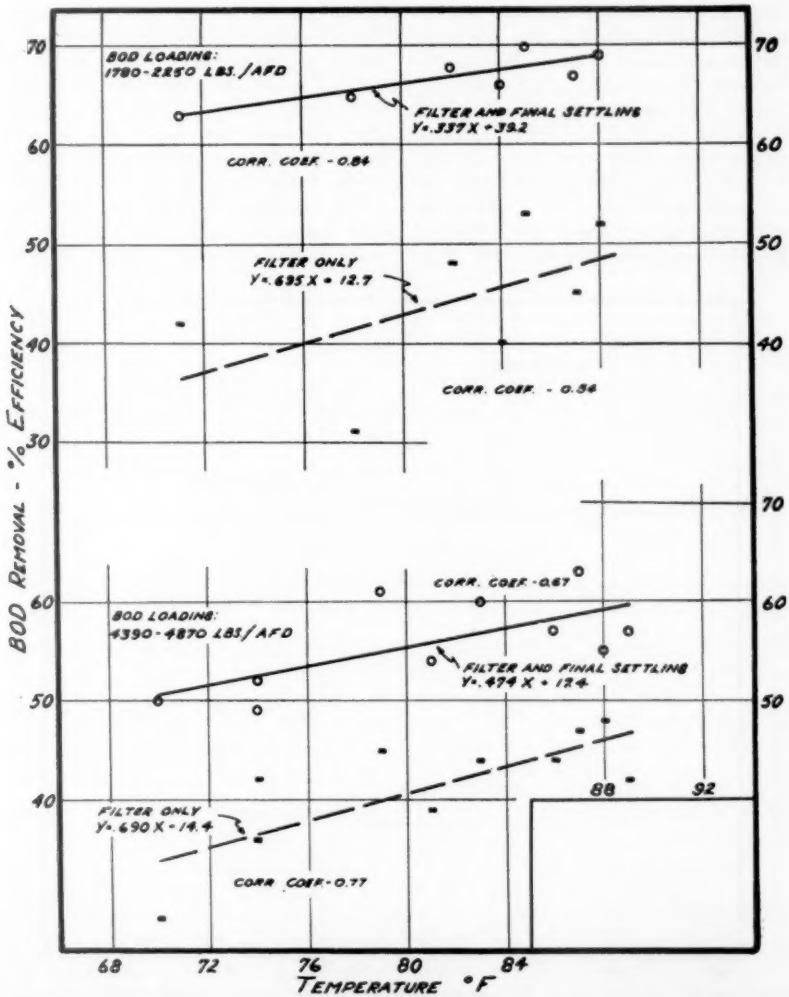


FIGURE 4.—Effect of temperature on filter efficiency; Fort Jackson, S. C., high-rate filter under two loading ranges, 1943–1945.

was returned, although the principal scheme of recirculation involved direct return of unsettled filter effluent. During the period under study, the average volume of recirculation was approximately 4 m.g.d., bringing the total load on the filters to roughly 7 m.g.d. Operating results from September, 1943, to December, 1945, were considered in this study. It was reported that operation was not completely stabilized prior to this period because of periodic construction activity. The loading and efficiency data tabulated are monthly average values representing daily composite samples.

In this case, the data afforded an excellent opportunity to eliminate, for all practical purposes, the effect of B.O.D. loading on filter efficiency. Two operating periods were found in which the filter loadings were unusually consistent; the values within each group were analyzed and plotted in Figure 4. The first group includes 10 selected months from December, 1943, to January, 1945, during which the filter loading varied only within the limits of 4,390 to 4,870 lb. B.O.D. per acre-foot per day. The second group comprises the 7 consecutive months from March, 1945, to September, 1945, inclusive, during which the filter loading varied only from 1,780 to 2,250 lb. B.O.D. per acre-foot per day. The results were gratifying; the correlations between values in these two groups were among the best obtained in this study.

Samples were also taken of the unsettled filter effluent, making it pos-

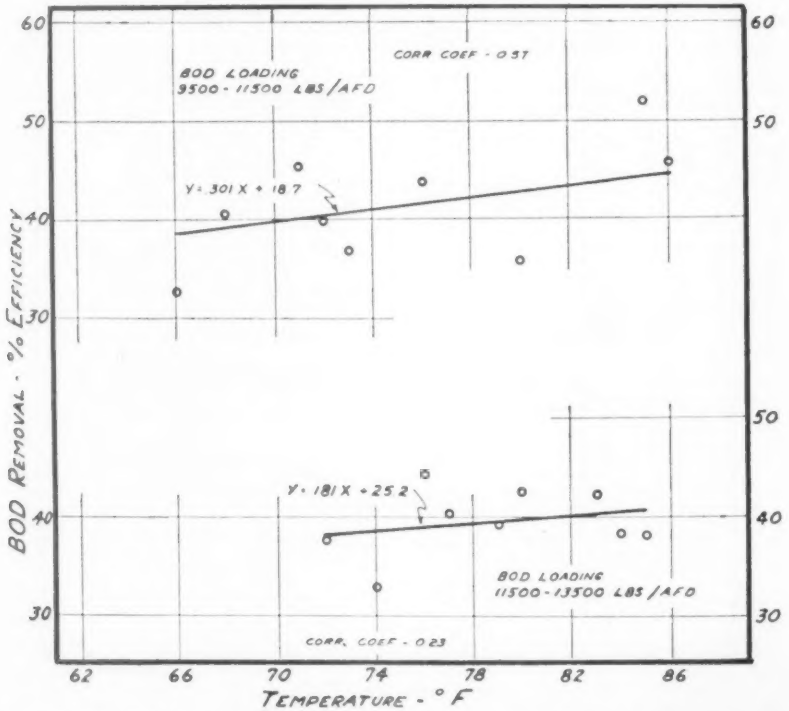


FIGURE 5.—Effect of temperature on filter efficiency; Austin, Minn., high-rate filter under two loading ranges, 1940–1942 and 1946–1948.

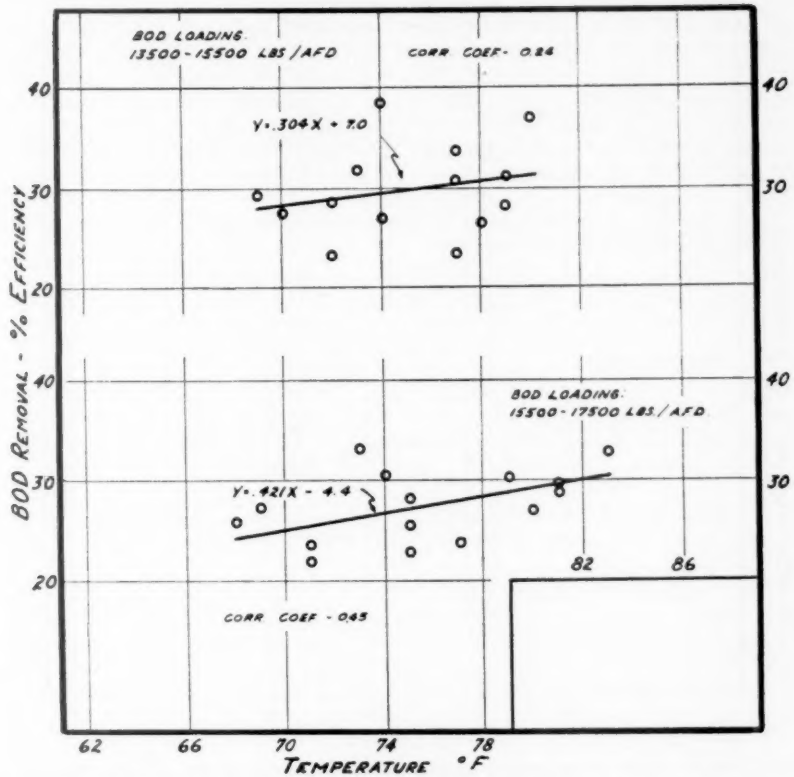


FIGURE 6.—Effect of temperature on filter efficiency; Austin, Minn., high-rate filter under two higher loading ranges, 1940–1942 and 1946–1948.

sible to compute the efficiency of B.O.D. removal by the filter alone. In this case, the filter alone was responsible for approximately 70 per cent of the total B.O.D. removal achieved by the filter and settling tank combined.

Austin, Minn.—The Austin sewage treatment works is a two-stage trickling filter plant receiving domestic wastes from a city of 25,000 and meat packing wastes which, even after pretreatment, have a population equivalent several times that of the domestic sewage load. Treatment of the combined waste begins with screening, flocculation, and primary sedimentation. At times of high load, alum may be added as a coagulant. Further treatment is provided by one pass through high-rate roughing filters, followed by intermediate sedimentation. The waste is then pumped to standard-rate filters equipped with a fixed-nozzle distribution system, after which it passes through a final sedimentation tank before being chlorinated and discharged to the receiving stream.

Monthly average operating results from March, 1940, to the end of 1942 were included in this study, as were those for the years 1946, 1947, and 1948. The intervening years were omitted because of plant operating difficulties and modification in the pre-

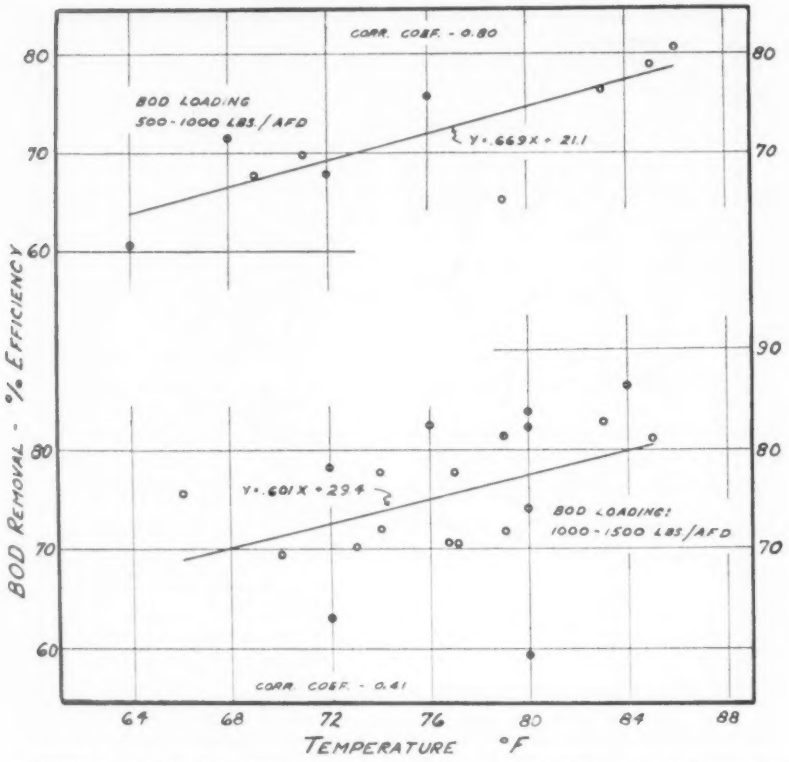


FIGURE 7.—Effect of temperature on filter efficiency; Austin, Minn., standard-rate filter under two loading ranges, 1940–1942 and 1946–1948.

treatment of meat packing wastes. The loading and efficiency values considered are monthly averages of 8 to 10 samples per month. In this case, the efficiency is that for filter and sedimentation tank combined. Raw sewage temperatures were recorded daily at 1 P.M.; the plant chemist stated that the sewage temperature dropped only slightly in passing through the plant in winter.

The two housed high-rate roughing filters have a combined area of 0.167 acres and are 6 ft. deep, providing a total capacity of 1.0 acre-ft. During the periods of study, the volume loading on these filters averaged approximately 21 m.g.a.d., while the B.O.D. loading ranged from less than 10,000 to more than 20,000 lb. per acre-foot per day. To eliminate the effect of this variation, the data were bracketed in loading groups limited to a 2,000-lb. range, such as 9,500 to 11,500 lb. per acre-foot per day, 11,500 to 13,500 lb. per acre-foot per day, etc. These limits were chosen to distribute the values as evenly as possible among the groups for statistical purposes. Four such groups, covering the loading range from 9,500 to 17,500 lb. per acre-foot per day, each included a sufficient number of values for analysis. Of the 65 monthly values available, 47 were included in these four groups, 13 fell below or above them,

and 5 were omitted because of operating difficulties. The effect of temperature on efficiency within the four loading groups is shown in Figures 5 and 6. In each case, the trend toward increasing efficiency with an increase in temperature is apparent, although the effect of temperature does not seem to be as great for filter loads in this range. The slopes of the lines of regression are quite consistent, varying only from 0.181 to 0.421.

The housed standard-rate filters have a total area of 0.88 acres and are 7.5 ft. deep, providing a total capacity of 6.6 acre-ft. During the pe-

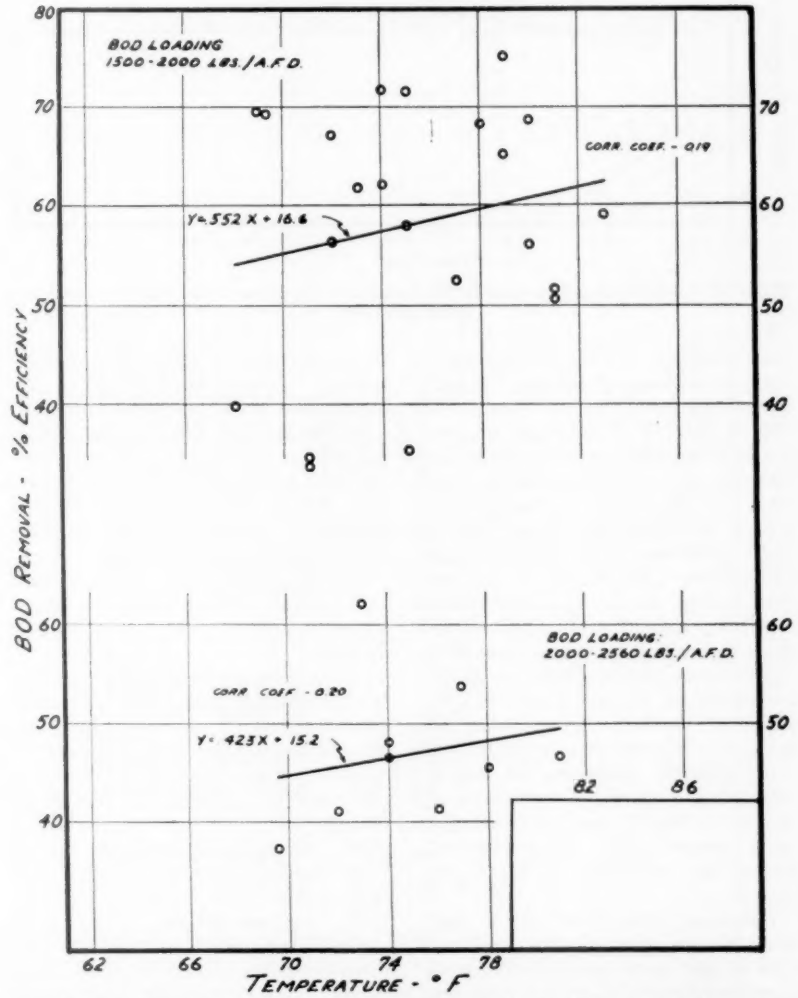


FIGURE 8.—Effect of temperature on filter efficiency; Austin, Minn., standard-rate filter under two higher loading ranges, 1940–1942 and 1946–1948.

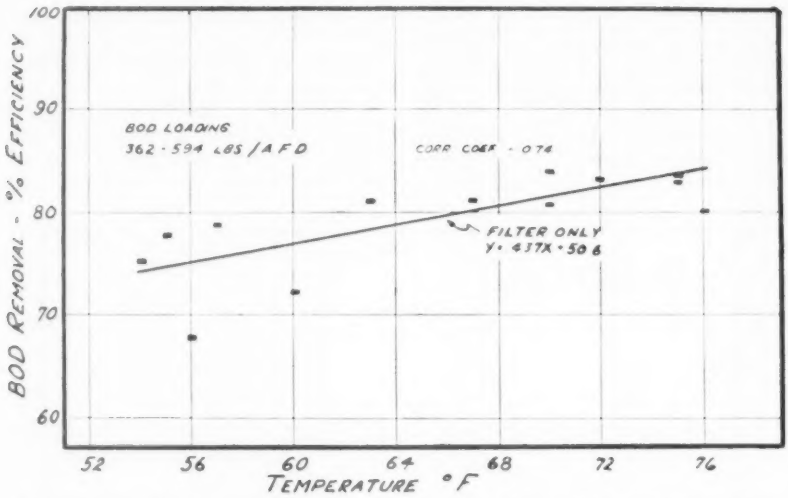


FIGURE 9.—Effect of temperature on filter efficiency; Baltimore, Md., standard-rate filter, 1938 and 1939.

riods of study, the volume loading on these units averaged roughly 4 m.g.a.d. Because the B.O.D. loading varied from 540 to 2,560 lb. B.O.D. per acre-foot per day, the values were again divided into four groups for analysis and plotting. In this case, the ranges were chosen arbitrarily as follows: 500 to 1,000, 1,000 to 1,500, 1,500 to 2,000, and 2,000 to 2,560 lb. B.O.D. per acre-foot per day. Of the 65 monthly values available, only 4 were omitted and these because of operating difficulties. Temperature effects within the groups are shown in Figures 7 and 8. The slopes of the lines of regression are again fairly consistent, varying from 0.423 to 0.669. However, the correlation between points in several of the groups is rather poor, showing that other factors besides temperature affected the efficiency of B.O.D. removal.

Baltimore, Md.—Part of the Back River sewage works of Baltimore consists of an open standard-rate trickling filter plant with a total filter area of 30 acres. From mid-1938 to mid-1939, approximately 0.1 acre was used in experimental work on high-rate filtration. During this period an adjacent area of 1.5 acres was operated as a control filter at an approximate rate of 3 m.g.a.d. The experimental filter area was loaded at rates varying from 6.5 to 30.0 m.g.a.d., making it difficult to analyze the effect on filter efficiency of temperature alone. However, temperature and efficiency data for the control filter were also determined and serve as the basis for this analysis.

After passing through bar screens, the raw sewage was given a primary sedimentation of approximately 2 hr. The settled sewage was then sprayed on the standard-rate control filter continuously by a fixed-nozzle distribution system. During the period under study, the average strength of the settled sewage reaching the filter was approximately 160 p.p.m. B.O.D.

The experimental work was carried out in 13 test periods of approximately three weeks each. Two or three times a week, 24-hr. composite samples of filter influent and unsettled effluent were collected and analyzed. A sta-

tistical study was made of the average values for each test period. The equation of the resulting line of regression (Figure 9) is $Y = 0.437\,X + 50.6$. This equation expresses the effect of temperature on the B.O.D. efficiency of the filter alone.

Summary of Results

The foregoing curves for individual groups of data are consistent in that each shows a trend of increasing efficiency for a rise in temperature. However, the groups of data represent a wide variation in filter loading, effi-

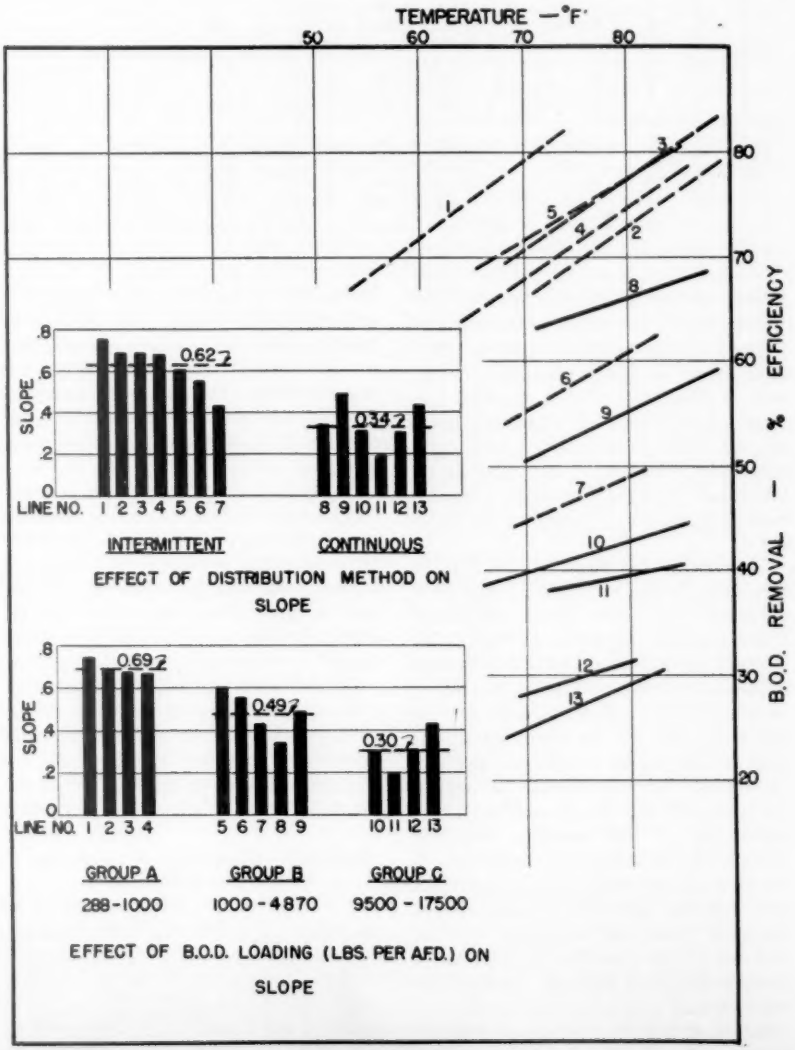


FIGURE 10.—Summary of temperature effect on efficiency of trickling filters.

TABLE III.—Summary of Effects of B.O.D. and Volumetric Loading on Slope or Regression Lines

Group	Line No.	Plant	Load Range (lb.)[1]	Slope	Vol. Load (m.g.a.d.)	Distr.	Group
A	1	Akron	288– 561	0.740	3.6	Int.	1
	2	Decatur	250– 400	0.680	3.2	Int.	
	3	Decatur	400– 550	0.673	3.3	Int.	
	4	Austin	500– 1,000	0.669	3.5	Int.	
B	5	Austin	1,000– 1,500	0.601	3.8	Int.	
	6	Austin	1,500– 2,000	0.552	4.0	Int.	
	7	Austin	2,000– 2,560	0.423	4.1	Int.	
	8	Ft. Jackson	1,780– 2,250	0.337	17.4	Cont.	2
	9	Ft. Jackson	4,390– 4,870	0.474	18.3	Cont.	
C	10	Austin	9,500–11,500	0.301	19.2	Cont.	
	11	Austin	11,500–13,500	0.181	20.4	Cont.	
	12	Austin	13,500–15,500	0.304	20.6	Cont.	
	13	Austin	15,500–17,500	0.421	21.8	Cont.	

[1] Pounds B.O.D. per acre-foot per day.

ciency, temperature conditions, and other factors, and cannot reasonably be lumped together to produce one "average" trend for all plants studied. Figure 10 shows the relative position and slope of each line of regression when all the lines (for filtering and sedimentation combined) are plotted on the same coordinate system. Similar summary data are presented in Table III.

To repeat, the slope of the line in this case is the measure of the temperature effect on filter efficiency. Upon a casual inspection of Figure 10, a question arises as to what factors influence the slope. Why is the slope, or temperature effect, as low as 0.18 per cent per °F. in some situations and as high as 0.74 per cent per °F. in others? Among the factors beyond the scope of this study are the characteristics of the sewage, physical characteristics of the filter, and operating procedures, such as sedimentation, recirculation, ventilation, and others. However, data are available for an analysis of the possible effect of three factors—B.O.D. loading, volumetric loading, and method of distribution.

Effect of B.O.D. loading on slope.—From an inspection of Figure 10 and Table III, it appears that the slope, or temperature effect, may be less at the high filter loads, which are reflected in lower efficiencies. To investigate this possibility, the data were arranged in load groups (Table IV) and an average slope was computed for each group.

The data definitely indicate that the temperature effect is of decreasing importance as the organic load in the filter becomes heavier. The average slope of the standard- or low-rate filters is more than twice that of the average of those in the roughing filter range.

Effect of volumetric loading on slope.—On a volumetric basis, the filter installations studied are either standard-rate units averaging 3 or 4 m.g.a.d. or high-rate filters averaging 17 to 22 m.g.a.d. The slopes for each group are

TABLE IV.—Effect of B.O.D. Loading on Slope of Line of Regression

Group No.	No. of Lines	Loading Range (lb.)[1]	Av. Slope
A	4	0– 1,000	0.69
B	5	1,000– 5,000	0.49
C	4	9,500–17,500	0.30

[1] Pounds B.O.D. per acre-foot per day.

TABLE V.—Effect of Volumetric Loading on Slope of Line of Regression

Group No.	No. of Lines of Regression	Filter Loading (m.g.a.d.)		Slope	
		Range	Av.	Range	Av.
1	7	3.2– 4.1	3.6	0.42–0.74	0.62
2	6	17.4–21.8	19.6	0.18–0.47	0.34

also quite consistent, as shown in Table V.

As the slope, or temperature effect, has been shown to decrease with an increase in either B.O.D. or volumetric loading, a question arises as to whether or not the effect of one of the two is fundamental and the effect of the other is then coincidental. At first thought, it might seem that the temperature effect would be of least importance on standard-rate filters because of the usual safety factor present at low B.O.D. loadings. Actually, when it is considered that the temperature of the slime is of prime importance and is the controlling factor in the rate of oxidation or B.O.D. removal, the volumetric loading takes on new significance. Many standard-rate filters are dosed intermittently: during rest periods the slime temperature undoubtedly moves toward the temperature of the air flowing through the filter bed; during dosing cycles it tends to move back toward the temperature of the sewage. Consequently, the mean slime temperature is likely to be somewhere between the temperature of the air and the sewage; in winter, it may be considerably lower than the sewage temperature, on which the study is necessarily based.

Therefore, it is probable that filter loading actually has little or nothing to do with the temperature effect; the temperature effect seems numerically greater at low filter loadings merely because of the intermittent dosing characteristic of standard-rate filter plants. Thus it is seen from a study of Figure 10 and Table III that the seven intermittently dosed filters (broken lines, Figure 10) have a temperature effect as represented by the slope of 0.62, whereas the continuously dosed filters (continuous lines, Figure 10) have a slope of only 0.34. A rise of 10° F. in sewage temperature, reflecting a much greater seasonal rise in mean air temperature, may mean twice as great a rise in the slime temperature of a standard-rate filter as in the slime temperature of a neighboring high-rate filter. Thus, the 10° F. rise in sewage temperature may result in a 6 or 7 per cent increase in the efficiency of the standard-rate filter and an increase of only 3 or 4 per cent in the efficiency of the high-rate filter. Based on the temperature of the slime rather than on that of the sewage, it is possible that the effect of temperature on the B.O.D. efficiency of a trickling filter is constant regardless of organic load.

Coefficients of correlation.—For those interested in the statistical approach, there is shown on each of the figures the calculated value of the coefficient of correlation, which, as already stated, is a measure of the success with which the line of best fit represents the individual data. For the combined effect of filtration and final sedimentation the coefficients of correlation for the different plants studied are as follows: Akron, Ohio, 0.75; Decatur, Ill., 0.73; Fort Jackson, S. C., 0.75; Austin, Minn., 0.39; and Baltimore, Md., 0.74. With the exception of the correlation at Austin, Minn., the data indicate a significant relationship between the plotted points and the calculated line of regression.

Nitrification.—Although several investigators have pointed out the fact that nitrification within a filter is accelerated by an increase in temperature, this phase of the problem was considered beyond the scope of the present paper.

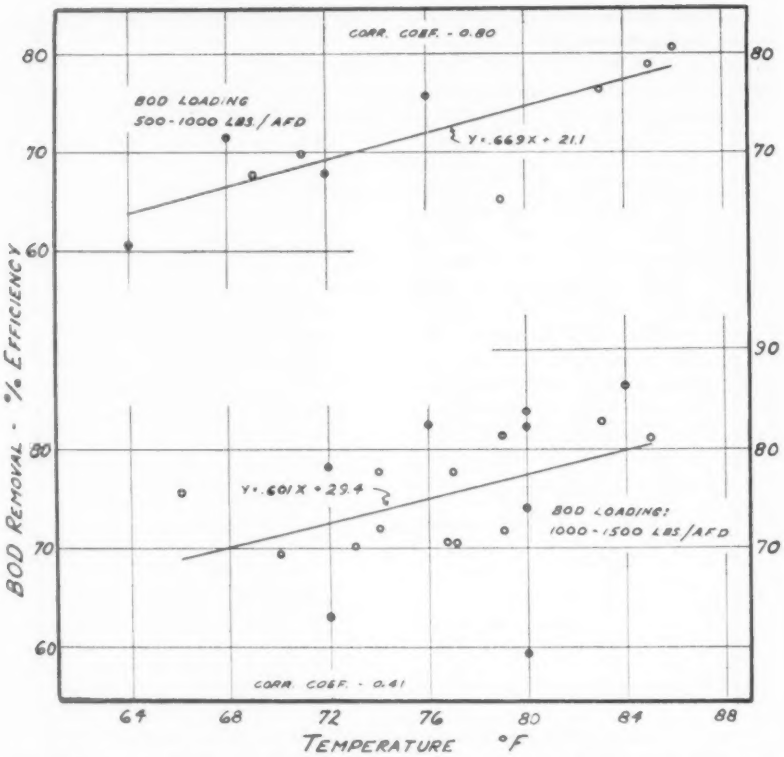


FIGURE 7.—Effect of temperature on filter efficiency; Austin, Minn., standard-rate filter under two loading ranges, 1940–1942 and 1946–1948.

treatment of meat packing wastes. The loading and efficiency values considered are monthly averages of 8 to 10 samples per month. In this case, the efficiency is that for filter and sedimentation tank combined. Raw sewage temperatures were recorded daily at 1 P.M.; the plant chemist stated that the sewage temperature dropped only slightly in passing through the plant in winter.

The two housed high-rate roughing filters have a combined area of 0.167 acres and are 6 ft. deep, providing a total capacity of 1.0 acre-ft. During the periods of study, the volume loading on these filters averaged approximately 21 m.g.a.d., while the B.O.D. loading ranged from less than 10,000 to more than 20,000 lb. per acre-foot per day. To eliminate the effect of this variation, the data were bracketed in loading groups limited to a 2,000-lb. range, such as 9,500 to 11,500 lb. per acre-foot per day, 11,500 to 13,500 lb. per acre-foot per day, etc. These limits were chosen to distribute the values as evenly as possible among the groups for statistical purposes. Four such groups, covering the loading range from 9,500 to 17,500 lb. per acre-foot per day, each included a sufficient number of values for analysis. Of the 65 monthly values available, 47 were included in these four groups, 13 fell below or above them,

and 5 were omitted because of operating difficulties. The effect of temperature on efficiency within the four loading groups is shown in Figures 5 and 6. In each case, the trend toward increasing efficiency with an increase in temperature is apparent, although the effect of temperature does not seem to be as great for filter loads in this range. The slopes of the lines of regression are quite consistent, varying only from 0.181 to 0.421.

The housed standard-rate filters have a total area of 0.88 acres and are 7.5 ft. deep, providing a total capacity of 6.6 acre-ft. During the pe-

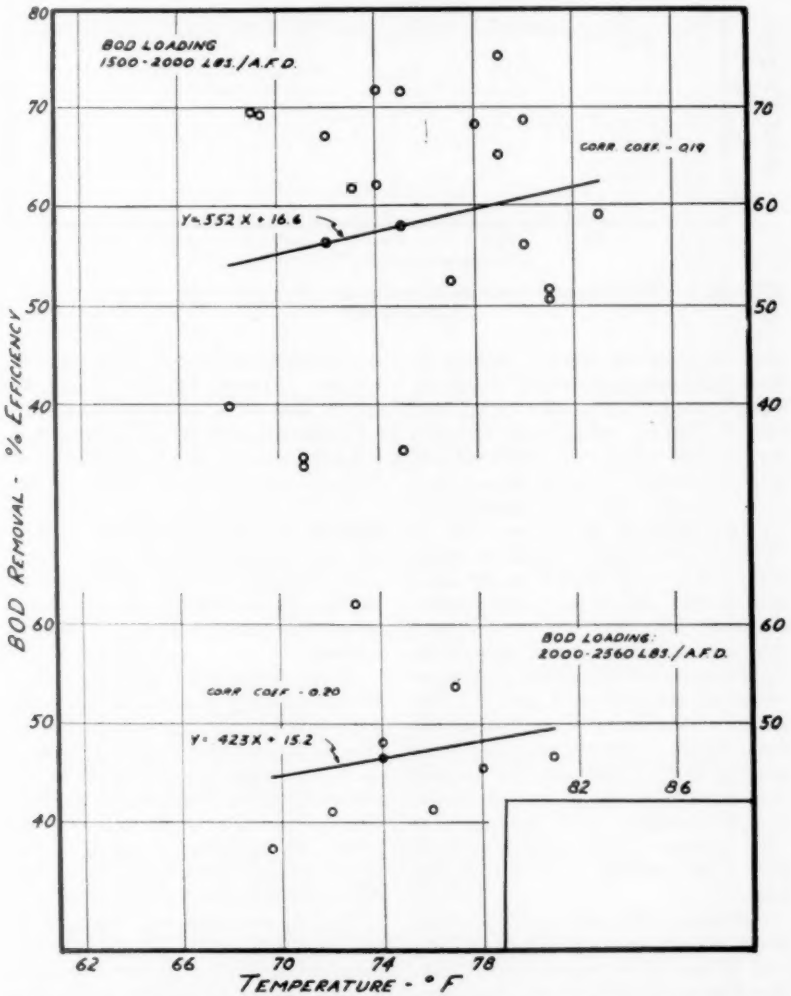
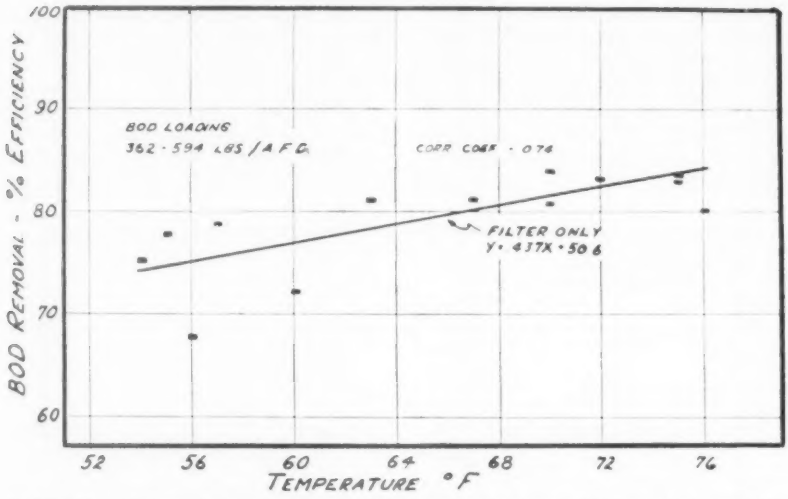


FIGURE 8.—Effect of temperature on filter efficiency; Austin, Minn., standard-rate filter under two higher loading ranges, 1940–1942 and 1946–1948.



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Baltimore, Md.—Part of the Back River sewage works of Baltimore consists of an open standard-rate trickling filter plant with a total filter area of 30 acres. From mid-1938 to mid-1939, approximately 0.1 acre was used in experimental work on high-rate filtration. During this period an adjacent area of 1.5 acres was operated as a control filter at an approximate rate of 3 m.g.a.d. The experimental filter area was loaded at rates varying from 6.5 to 30.0 m.g.a.d., making it difficult to analyze the effect on filter efficiency of temperature alone. However, temperature and efficiency data for the control filter were also determined and serve as the basis for this analysis.

After passing through bar screens, the raw sewage was given a primary sedimentation of approximately 2 hr. The settled sewage was then sprayed on the standard-rate control filter continuously by a fixed-nozzle distribution system. During the period under study, the average strength of the settled sewage reaching the filter was approximately 160 p.p.m. B.O.D.

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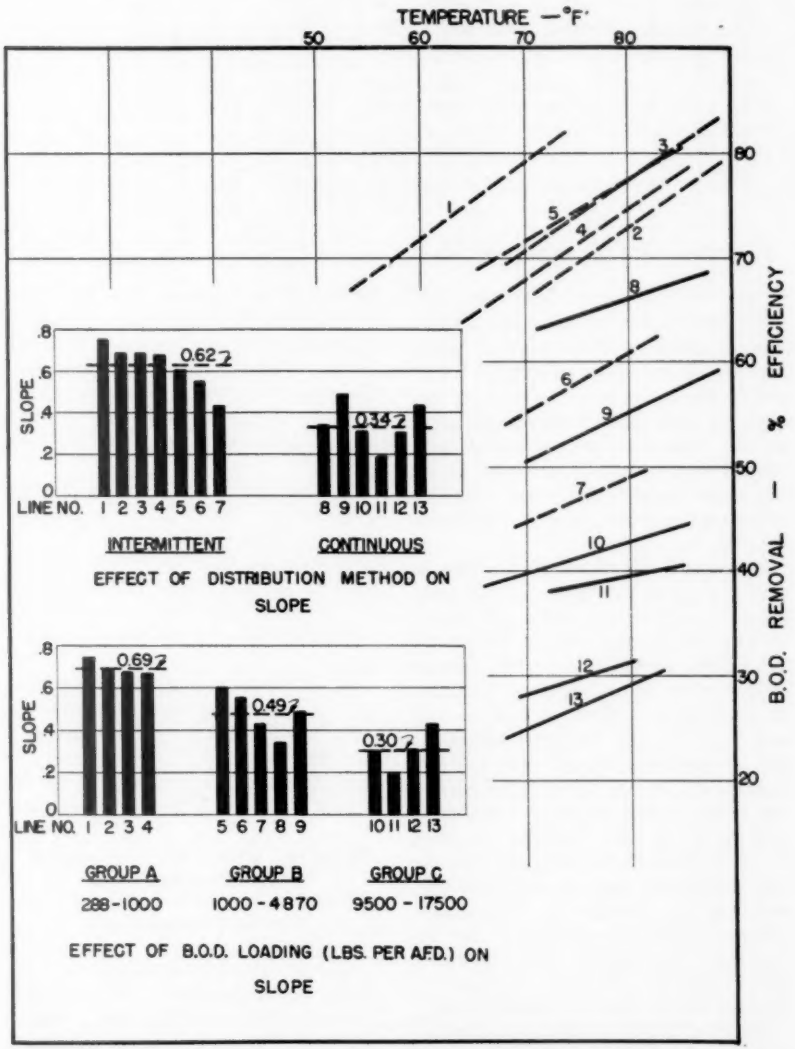

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CONSTRUCTION CONTROLS RELAXED!

In a communication received just prior to closing this issue, G. E. Arnold, Director of the Water Resources Division, NPA, has called attention to an advance release that CMP Regulation 6, the basic construction order, would be somewhat relaxed by an amendment to become effective July 1, 1952. Of particular importance to water and sewage works operators is the liberalization of self-certification by reclassification of water and sewage system construction from the commercial to the industrial category.

In interpreting the amendments in light of previous orders and regulations, Mr. Arnold said:

". . . Under this proposal, the sewage works operators will be permitted to self-certify construction projects containing the following quantities of materials: Up to 25 tons of steel, including all types of structural shapes but not including more than 2½ tons of alloy steel and no stainless steel. They may self-certify 2,000 lb. of copper and copper-base alloys and 1,000 lb. of aluminum. Dollar value for construction and building materials will be $100,000 and for production equipment and production machinery $200,000. These figures compare with the present limitation of 5 tons of steel, 200 lb. of copper, $15,000 of building equipment and building materials, and $5,000 of production equipment. . . .

"This relaxation of the self-certification limitation will have the effect of producing the number of applications filed with the Water Resources Division by about 40 per cent, as most small operators will be able to self-certify their construction projects. . . ."

"All of the above is predicated on there being no serious steel strike. If there is a serious steel strike, a revision of the orders to tighten them will immediately follow. . . ."

PERFORMANCE OF HIGH-RATE TRICKLING FILTERS OPERATED IN SERIES AND IN PARALLEL *

By H. Heukelekian, C. B. McMenamin, and M. C. Rand

Respectively, Research Engineer, N. J. Agricultural Experiment Station; Superintendent, Middlesex Borough Sewage Treatment Plant, Bound Brook, N. J.; and Research Associate, N. J. Agricultural Experiment Station, Rutgers University, New Brunswick, N. J.

There are a great number of high-rate trickling filters in existence in this country, and considerable information is available on the operating results, loadings, and efficiencies of such filters. A number of the installations employ double filtration. In some, the primary filter is of the high-rate type, followed by a low-rate filter. In others, both units may be of the high-rate type. Some of the installations practice recirculation; others do not. However, despite the number and variety of high-rate filters upon which data are available, there are few direct comparisons of single-stage filtration with double-stage filtration on the basis of efficiencies at different loadings.

It has been established that two-stage high-rate filters give effluents which compare favorably with standard-rate filters, and even with activated sludge. Also, that they are distinctly superior to single-stage high-rate filters. The question raised in this paper, however, does not concern itself with these comparisons, but with the problem of the efficiency of a cubic yard of filter stone in single *vs.* double filtration. The question that is specifically raised is, if two filters are available which can be operated either as single-stage units in parallel or double-stage units in series, which type of treatment would give the highest efficiency with the same sewage and loadings; or, if a new plant were to be built, can the over-all size of the filters be reduced by designing a double filtration type rather than a single filtration and still obtain the desired quality of effluent. It is the purpose of this paper, therefore, to present a comparison of the results obtained in series and parallel operation of a pair of experimental high-rate filters.

The experimental units were set up at the Middlesex Borough sewage treatment plant. The plant is equipped for treatment by sedimentation and chlorination of sewage, augmented during the summer months by chemical coagulation. The dry-weather flow at the plant is 600,000 g.p.d., derived mainly from domestic sources except for 60,000 g.p.d. of waste discharged from a candied fruit manufacturing plant. The waste is high in sugars, B.O.D., and dissolved solids. The discharge of this waste into the municipal sewer increases the B.O.D. of the mixture considerably, making it difficult to obtain a desirable quality of effluent with the primary treatment facilities available, even after chemical coagulation. To meet this situation, secondary treatment of the combined domestic and industrial waste is one of the alternatives. Accordingly, the experimental filters were operated at this plant for two purposes: (1) to obtain the fundamental information mentioned above, and (2) to meet a local situation.

* Paper of the Journal Series, New Jersey Agricultural Experiment Station. Presented at 1951 Annual Meeting, Pennsylvania Sewage and Industrial Wastes Assn.; State College, Pa.; August 22–24, 1951.

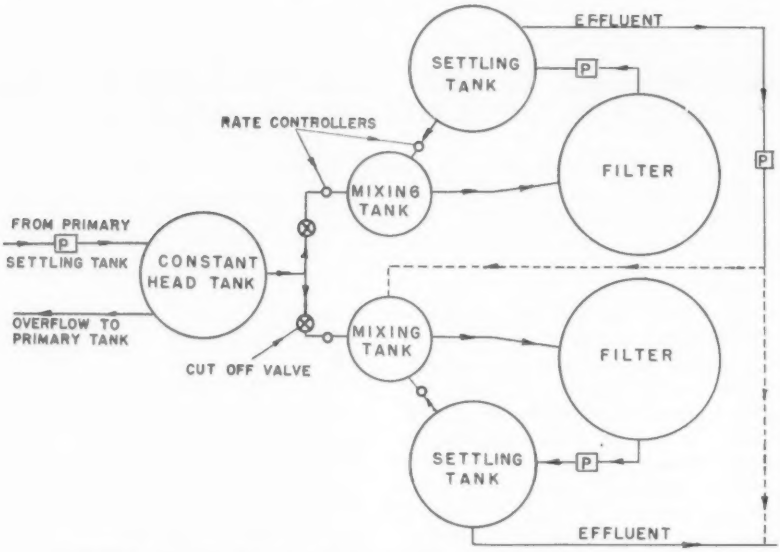

FIGURE 1.—Flow diagram of experimental high-rate trickling filter plant.

Experimental Apparatus

Figure 1 is a diagram of the experimental equipment, which consists essentially of two trickling filters 15 ft. in diameter and 5 ft. deep, each followed by an upward-flow sedimentation tank. The two units may be operated either in series or in parallel.

Settled sewage from the effluent channel of the primary clarifier of the plant proper is pumped to a constant-head tank, from which the overflow is returned to the primary clarifier. The flow from the constant-head tank to the trickling filters is controlled by valves and orifice discs inserted in the lines to the mixing tanks.

Recirculation is likewise controlled by orifice discs, which regulate the flow from the clarifiers to the mixing tanks.

Sludge from the settling tanks is returned to the primary clarifier of the plant proper.

When the two filters are operated in parallel, settled sewage from the constant-head tank is allowed to flow into both the mixing tanks. The effluent from the filters is lifted to the sedimentation tanks. From each sedimentation tank a portion of the settled effluent, controlled by an orifice disc, is returned to the corresponding mixing tank for recirculation. The overflow from both settling tanks passes to the effluent channel.

For series operation, settled sewage from the constant-head tank is admitted to only one of the mixing tanks. Recirculation is accomplished the same as in parallel operation. However, the overflow from the settling tank following the primary filter is diverted to the mixing tank of the secondary filter. The effluent from the secondary filter passes to the corresponding settling tank, a portion is recirculated to the mixing tank, and the overflow from the settling tank goes to the effluent channel.

Procedure

The filters were operated from May to November during 1947, 1948, 1949,

and 1950. The filters were operated in parallel during the first two years, and in series during the last two years. More data were obtained during parallel operation, as each filter during the period was dosed at a different volumetric rate and a different B.O.D. loading. The dosage rates were changed from time to time during both single- and double-stage operation periods. Loadings also varied because of fluctuations in the B.O.D. of the applied sewage. Recirculation ratios were also varied from time to time during the entire period of operation.

Once or twice a week samples of the settled sewage and of the influent and effluent of each filter were taken and the 5-day 20° C. B.O.D.'s determined. Each sample so tested was a composite of samples taken hourly from 11 A.M. to 3 P.M., during which time the strength of the sewage applied to the filters was slightly above the daily average, although peak strength did not always occur during those hours. Candied fruit waste was always present in the sewage during the sampling period, which, therefore, represents the most difficult conditions for treatment.

Strength of Sewage Applied

The strength of the sewage applied to the filters was high because of the presence of candied fruit wastes. During the single-stage operation period, the average B.O.D. of 81 samples of applied sewage was 540 p.p.m., with a minimum of 135 p.p.m. and a maximum of 830 p.p.m. During the double-stage operation period, the average B.O.D. of 55 samples of sewage applied was 628 p.p.m., with a minimum of 315 p.p.m. and a maximum of 1,200 p.p.m. The strength of the applied sewage was about 3 to 4 times higher than that of normal domestic sewage, and the strength was somewhat less during the period of single-stage operation than during double-stage filtration.

Although the candied fruit waste is deficient in nitrogen, no artificial supplementation was practiced. Since no deficiency was encountered, presumably the mixture of the waste with domestic sewage contained sufficient nitrogen for optimum biological treatment.

Results

The average results of parallel and series operation for the entire period are given in Table I. The volume of applied sewage was 3.8 m.g.a.d. during parallel operation and 3.1 m.g.a.d. during series operation. The recirculation ratio was 3.6 during parallel operation and 6.0 during series operation, including the recirculation in both primary and secondary filters. The total hydraulic load on the filter during parallel operation was 17.5 m.g.a.d., and 21.7 m.g.a.d. during series operation. The B.O.D. of the applied sewage was 540 p.p.m. and 628 p.p.m., respectively, for parallel and series operations. These high B.O.D.

TABLE I.—Average Results Obtained During Parallel and Series Operation Periods

Operation	No. of Tests	Volume[1] Applied (m.g.a.d.)	Recirc. Ratio	B.O.D.			
				Applied (p.p.m.)	Applied (lb.)[2]	In Effl. (p.p.m.)	Red. (%)
Parallel	81	3.8	3.6	540	2.6	110	80
Series[3]	55	3.1	6.0	628	2.5	39	89

[1] Volume of untreated waste, excluding recirculation.
[2] Pounds B.O.D. per cubic yard per day.
[3] Volume of sewage and recirculated water and B.O.D. load applied are on the basis of a unit volume of stone in both primary and secondary filters.

TABLE II.—Results of Parallel Operation

Loading (lb. B.O.D.)[1]	No. of Tests	Volume Applied (m.g.a.d.)	Recirc. Ratio	B.O.D.	
				Eff. (p.p.m.)	Red. (%)
1.0	5	2.6	6.1	51	79.5
1.0–1.5	16	1.8	4.8	60	88.2
1.6–2.0	14	2.8	4.5	65	87.4
2.0–2.5	15	3.2	4.4	90	83.5
2.6–3.0	6	4.4	3.6	97	82.2
3.1–3.5	6	6.3	2.3	162	68.7
3.6–4.0	6	5.5	2.2	194	66.1
4.1–4.5	4	5.3	2.2	186	69.5
4.6–5.0	5	6.4	2.2	197	66.5
5.1–6.0	4	6.4	2.0	234	65.4

[1] Pounds B.O.D. per cubic yard per day.

values of the settled applied sewage reflect the influence of the candied fruit waste discharged into the municipal sewer. The B.O.D. loads applied during the two periods were nearly alike at 2.5 lb. per cu. yd. per day. However, the effluent during single-stage operation had a B.O.D. of 110 p.p.m., and during parallel operation 39 p.p.m., giving 80 and 89 per cent B.O.D. reductions, respectively, by secondary treatment.

The results are grouped in ranges of B.O.D. loading in Table II for parallel operation, and in Table III for series operation. The recirculation ratios were high for low loadings and decreased with higher loadings. This was not intentional; it would have been more logical either to keep the recirculation ratios constant for different loadings or to increase them with higher loadings. It was, however, dictated by pump capacity, which did not permit higher rates of application of sewage with higher recirculations. It is hoped that in future experiments results will be obtained indicating the effect of different rates of recirculation at critical loadings to determine the minimum recirculation with maximum loadings without deteriorating the quality of the effluent.

TABLE III.—Effect of Increased Loading on the Quality of the Effluent in Series Operation

Loading (lb. B.O.D.)[1]	No. of Tests	Volume Applied (m.g.a.d.)	Recirc. Ratio	B.O.D.	
				Eff. (p.p.m.)	Red. (%)
1.0	2	1.6	10.2	21	96
1.0–1.5	9	2.4	8.3	20	96
1.5–2.0	9	2.5	8.0	19	96
2.0–2.5	8	3.0	5.84	22	96
2.5–3.0	8	3.5	4.7	43	92
3.0–3.5	9	3.7	4.4	42	93
3.5–4.5	8	4.2	5.0	75	88
4.5–5.5	2	4.0	4.0	69	93

[1] Pounds B.O.D. per cubic yard per day.

Table II shows that the B.O.D. of the effluent increased quite regularly with increasing loading. The rate of change of effluent B.O.D. is not quite constant, but shows a distinct break at a loading of 3.0 lb. per cubic yard per day. This break is also reflected in the percentage reduction. At loadings of 1 to 3 lb., the removal averages more than 80 per cent. However, when the loading is increased to more than 3 lb. per cubic yard, the reduction drops abruptly to a value of less than 70 per cent, and remains fairly constant in the range from 65 to 70 per cent throughout the range of loadings tested.

Table III shows the results of 2 years' series operation. The loadings are calculated on the basis of the total volume of media in both filters. In series operation, both the effluent B.O.D. and the percentage B.O.D. removal are approximately constant up to a loading of 2.5 lb. per cubic yard per day. Above that loading, the effluent B.O.D. increases, without a material decrease in the percentage reduction.

A comparison between series and parallel operation is shown graphically in Figure 2. It is clear that parallel operation gives a higher B.O.D. in the effluent for any given loading. At a loading of 1 lb. per cubic yard per day the effluent from parallel operation has about twice the B.O.D. of the

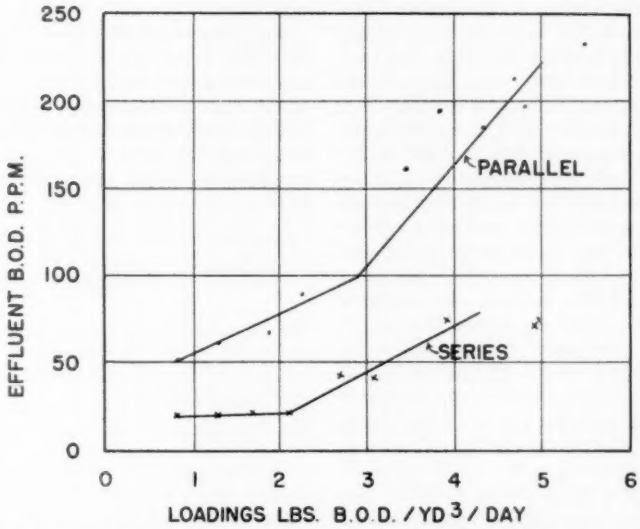

FIGURE 2.—Comparison of the effect of loading on the B.O.D. of effluent in series and parallel operations.

effluent produced by series operation. At a loading of 4 lb. the factor is about 2; but with loadings between 1 and 2.5 lb. the effluent B.O.D. in series operation is about constant, whereas in parallel operation there is a gradual increase of effluent B.O.D. with increasing applied load. At a loading of 2.5 lb. per cubic yard per day, the most efficient point for series operation, the effluent B.O.D. produced by series operation is only one-third that produced by operating the filters in parallel. Thus, at any loading between 1 and 4 lb. of B.O.D. per cubic yard per day, the effluent B.O.D. from parallel operation averaged 2 to 3 times as high as that produced by series operation.

It follows, from what has been said, that a given effluent standard permits higher loadings in series operation than in parallel operation. For example, an effluent standard of 100 p.p.m. B.O.D. could be met by operating the filters in parallel at a loading of 2.75 lb. per cubic yard, or by operating them in series at a loading of 4.25 lb. On the other hand, an effluent of 20 p.p.m. B.O.D. could be produced by operating the filters in series at a loading of 2.5 lb., whereas no loading in the range tested was low enough to produce consistently an effluent of this quality in parallel operation.

Discussion

The results of this study show that double filtration systems can handle greater B.O.D. loadings and give lower B.O.D. values in the effluent than can be accomplished by single filtration. For instance, with a loading of 2.5 lb. of B.O.D. per cubic yard of stone, a 20-p.p.m. B.O.D. in the effluent could be obtained with double filtration, whereas with the lowest loading obtained with single filtration, 1.0 lb. per cubic yard, the B.O.D. in the effluent was 50 p.p.m. In other words, the efficiency of a cubic yard of stone is at least 2.5 times as great when used in double filtration as it is in single filtration. It should be noted that

the loadings given in the double filtration are on the basis of total volume of media in both primary and secondary filters combined. The effluent quality in the loading range from 1 to 2.5 lb. per cubic yard per day is constant at 20 p.p.m. B.O.D. with double filtration. Beyond this range it gradually increases with increasing loading until at about 4.5-lb. loading it reaches 75 p.p.m. The increase in the effluent B.O.D. in the single-stage filtration starts at 1.0-lb. loading and increases gradually until at 4.5-lb. loading it reaches 200 p.p.m. To obtain a 50-p.p.m. B.O.D. in the effluent the B.O.D. loading in the single-stage filtration cannot exceed 1.0 lb. per cubic yard, whereas the same quality of effluent can be obtained with double-stage filtration at a loading rate of 3.0 lb. per cubic yard. The question may be raised as to whether the observed superiority of series operation may not be attributed to the higher over-all recirculations practiced during that period. Although the results do not warrant a positive assertion on this point, it does not seem that an increase in the average recirculation ratio from 3.6 during the parallel operation period to 6.0 during the series operation period could account for the differences obtained, because the lower recirculation ratio should prove adequate and increasing the recirculation beyond this should not be of additional value. Furthermore, the total hydraulic loads were 17.5 and 21.7 m.g.a.d., respectively, during parallel and series operation—well beyond the critical flows of 7 to 12 m.g.a.d. A closer analysis reveals that the effluent B.O.D. was 51 p.p.m. during parallel operation with a loading less than 1.0 lb. B.O.D. per cubic yard per day and with a recirculation ratio of 6.1; in series operation a B.O.D. in the effluent of 22 p.p.m. was obtained with 2.0 to 2.5 lb. B.O.D. per cubic yard per day (average, 2.1) and with a recirculation ratio of 5.8. Thus, with nearly equal recirculation ratios better effluents were obtained at more than double the loadings in series operation than in parallel operation. Similar relationships were obtained from results in which nearly equal recirculation ratios are available during the periods of parallel and series operations, as follows:

Recirculation Ratio		Loading (lb. B.O.D./ cu. yd./day)		Effluent B.O.D. (p.p.m.)	
Parallel	Series	Parallel	Series	Parallel	Series
6.1	5.8	1.0	2.1	51	22
4.8	4.7	1.3	2.7	60	43
4.4	4.4	2.2	3.1	90	42

It would, however, be desirable to confirm this point in order to eliminate the possibility of superior performance of series operation arising from the higher recirculation ratios employed.

Information obtained from experiments conducted at Birmingham, England, over a number of years (4) (7) with the comparison of single-stage *versus* double-stage filtration with periodic change in the order of filters in series operation, indicates that the volumetric dose on single filters could not be increased beyond 96 gal. (U. S.) per cubic yard per day without impairing the quality. Effluents with comparable quality could be obtained with double alternating filters with rates of application as high as 288 to 300 gal. (U. S.), again a ratio of efficiency 3 times as high as the single-stage filter. True, even these higher rates of volumetric applications on alternating double filtration when translated to loading rates give values of only 0.4 lb. B.O.D. per cubic yard, which is in the upper range of loading of standard filters in the United States. The effluents in the Birmingham experiments had a B.O.D. of 10 p.p.m. and nitrate-nitrogen of 20 p.p.m., as compared with the 25 p.p.m. B.O.D. obtained in the experiments reported

herein with double filtration at a loading value of 2.5 lb. per cubic yard. It is also true that these results in England were accomplished with periodic alternation in the order of filters, otherwise the filters would clog and deteriorate, whereas at no period of the current study, either with single-stage or double-stage operation, was there any indication of clogging. This may be ascribed to the fact that recirculation was practiced instead of alternation.

A study of two-stage fixed sequence *versus* single-stage biological filtration, both in enclosed artificially ventilated deep filters as reported by Dekema and Krige (2) from South Africa is also of interest in comparison with the results reported herein, despite the obvious differences in the design of filters in the two studies. The authors concluded that 33.8 per cent more flow could be applied and 31 per cent greater removal of B.O.D. accomplished per cubic yard of stone in two-stage filtration than in single-stage with equal purification.

Fischer and Thompson's (3) results dealing with the shallow recirculated filters at Petaluma, Calif., are, on the other hand, somewhat inconclusive in establishing the relative efficiencies of the two types of filters because on the basis of relatively few analyses, the average figures give 110 p.p.m. B.O.D. in the effluent with 5.9 lb. loading per cubic yard per day with single-stage, and 35 p.p.m. B.O.D. in the effluent with 3.1 lb. B.O.D. per cubic yard applied on the two-stage unit. The lower B.O.D. values in the two-stage systems cannot be definitely attributed to double filtration, because they were accomplished with lower loadings than in the single-stage operation.

It is similarly difficult to draw conclusions as to the relative merits of double filtration *vs.* single filtration on the basis of the results obtained at Liberty, N. Y. (1), as the filters here are operated throughout the year in series, except that in winter lower loadings are applied and recirculation is not practiced.

Walton (6) concluded that single-stage filtration gives an over-all 75 to 85 per cent B.O.D. reduction, with an average of less than 80 per cent for the plants studied. For two-stage filtration, the over-all B.O.D. reduction ranged from 85 to 95 per cent, with an average of 90 per cent.

Moore, Smith, and Ruchhoft (5) showed that with nearly equal loadings (2.4 lb. B.O.D. per cubic yard) the B.O.D. in the final effluent from single-stage operation was 31 p.p.m. and that from double-stage operation was 24 p.p.m.

Summary and Conclusions

Two experimental filters 15 ft. in diameter and 5 feet deep were operated for two seasons from May to November on the basis of parallel operation and for two additional seasons on the basis of series operation. Recirculation was practiced. The loadings were varied by (a) changing the flows periodically and (b) fluctuations of B.O.D. in the applied sewage. The sewage contained candied fruit waste containing sugar and high soluble B.O.D. The average B.O.D. of the applied sewage was 540 p.p.m. during single-stage operation and 628 p.p.m. during double filtration. The results based on the B.O.D. of the effluents warrant the following conclusions:

1. The efficiency of the double filtration system was 2.5 to 3 times as high as that of single filtration.

2. A loading of 1 lb. of B.O.D. per cu. yd. per day gave an effluent with a B.O.D. of 50 p.p.m. in single-stage filtration, whereas with double-stage filtration a 20-p.p.m. B.O.D. was obtained in the effluent with a loading as high as 2.5 lb. B.O.D. per cubic yard per day.

3. Between 1 to 2.5 loading range,

double filtration gave constant B.O.D. values in the effluent, with higher loads resulting in a gradual increase in B.O.D. of the effluent. In single-stage filtration the B.O.D. in the effluent began to increase with loadings above 1.0 lb. per cubic yard per day.

4. Ponding troubles were not encountered with either system of operation at any loading.

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MAKE YOUR HOTEL RESERVATIONS FOR THE FSIWA SILVER ANNIVERSARY MEETING

The Hotel Statler at New York City will be the headquarters for the Federation's Twenty-Fifth Annual Meeting, to be held in October. An outstanding Silver Anniversary program is being planned for the four-day meeting.

Requests for room reservations should be addressed directly to the hotel. It should be noted that the technical program will open on Monday morning, October 6, and will close at noon on Thursday, October 9. However, the usual inspection trip will this year be scheduled for the afternoon of October 9, after the close of the meeting.

WRITE NOW FOR YOUR RESERVATIONS!

Industrial Wastes

BENCH-SCALE BIOLOGICAL OXIDATION OF REFINERY WASTES WITH ACTIVATED SLUDGE

By R. H. Coe

Technologist, Shell Oil Co., Wilmington, Calif.

The organic contaminants usually found in the waste water of a petroleum refinery are likely to include hydrocarbons, phenols, carboxylic acids, nitrogen compounds, and sulfur compounds. Numerous other substances, such as ethers, ketones, and aldehydes, can be present, particularly if the over-all operation includes a petroleum-chemical manufacturing plant. Very small amounts of some of these compounds can be toxic *per se* to marine organisms in the stream receiving the waste water, and the oxidizable compounds would, of course, be toxic to the extent that they deplete the oxygen in the receiving stream. Furthermore, the waste water usually has characteristics of odor and color which require improvement from an esthetic point of view.

The use of trickling filters for treatment of petroleum refinery waste water has been briefly reported (1), the removal of "oil" and B.O.D. being on the order of 80 to 85 per cent. An activated sludge plant, although it may offer advantages of smaller size and lower cost, is expected, in general, to require more careful control than a trickling filter and to be more susceptible to upset from variations in the composition of the waste water undergoing treatment. Nevertheless, in view of the marked success encountered in biological treatment with activated sludge of waste water containing many different kinds of organic substances, a program of study was undertaken to determine the feasibility of treatment of petroleum refinery effluent by the activated sludge process.

The waste water used in this study came from several or all of the following principal types of petroleum refinery units: thermal cracking, catalytic cracking, naphthene and butane isomerization, alkylation, acid treating, solutizer sweetening, benzene and toluene manufacture, alcohol and ketone manufacture, and cresylic acid manufacture. Domestic sewage was not included. The waste water used in the experimental work usually had the following approximate composition:

	Average	Usual Limits
pH	8	7.5–8.5
Inorg. salts (p.p.m.)	3,500	3,200–4,300
Phenols (p.p.m.)	100	50–175
Permanganate O_2 cons. (p.p.m.)	500	300–1,050
B.O.D., 5-day (p.p.m.)	1,100	650–1,600
"Oil" (p.p.m.)	25	20–30

Description of Bench-Scale Treatment Unit

A bench-scale unit for treatment with activated sludge was devised which permitted continuous feeding of waste water and continuous removal of treated product. It was considered that continuous feeding would be more desirable than batch-wise feeding, which is conventionally employed in laboratory-scale activated sludge systems, and that continuous feeding should more closely simulate commercial practice. Furthermore, it was

thought that shock dosage of the floc in an experimental treatment unit by batch-wise feeding should be avoided, especially in the case of a feed such as refinery waste water, which contains chemical toxicants.

Each bench-scale unit consisted of a feed tank, a peristaltic pump for delivering feed to the aerator, an aerator and attached settler, and a product receiver. A view of the apparatus, comprising six units, is shown in Figure 1.

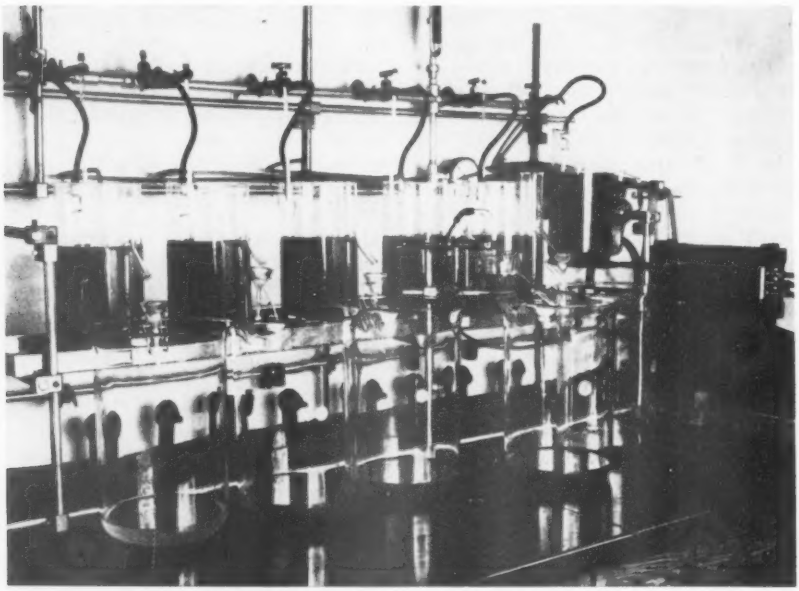

FIGURE 1.—Arrangement of apparatus for continuous bench-scale treatment with activated sludge.

The feed pump was a Sigmamotor Pump, Model T–6, made by E. and M. Enterprises, Inc., of Middleport, N. Y. In this pump, rubber tubing containing the fluid to be pumped is held between a fixed plate and a series of fingers which squeeze the rubber tubing against the back-up plate in sequence to "milk" the fluid through the tubing. The rubber-tubing mounting of the pump was modified to permit simultaneous pumping of different waste waters through six 3/16-in. i.d. rubber tubes. In addition, the tubes were mounted so as to allow adjustable stretching of each individual rubber tube up to 20 per cent, thus achieving close control of the flow rate in each system and a maximum decrease in flow rate of up to 50 per cent at constant speed of the pump. This pumping system is not only simple in principle, but is remarkably dependable and free from maintenance problems.

A close-up of a 1,500-ml. aerator-settler is shown in Figure 2, and details of its construction are given in Figure 3. Feed was introduced at a predetermined rate into the aerator, and product was allowed to overflow from the spout on the side of the settler. The mixed liquor in the aerator was agitated by air delivered through a bubbler of sintered glass located on the bottom of the aerator. It was found that the suspended solids which

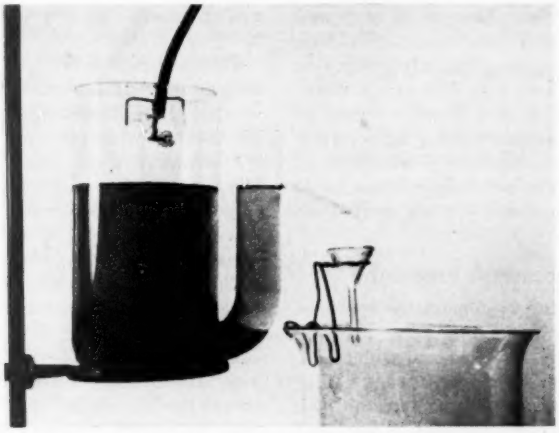

FIGURE 2.—Close-up of aerator-settler unit.

settled in the settler were continuously reintroduced to the aerator by the turbulence which normally extended into the lower third of the settler. The product was collected in a 4-l. beaker after being filtered through a small plug of glass wool to remove any suspended solids that might have carried through the settler.

The feed holders were calibrated 2.5-

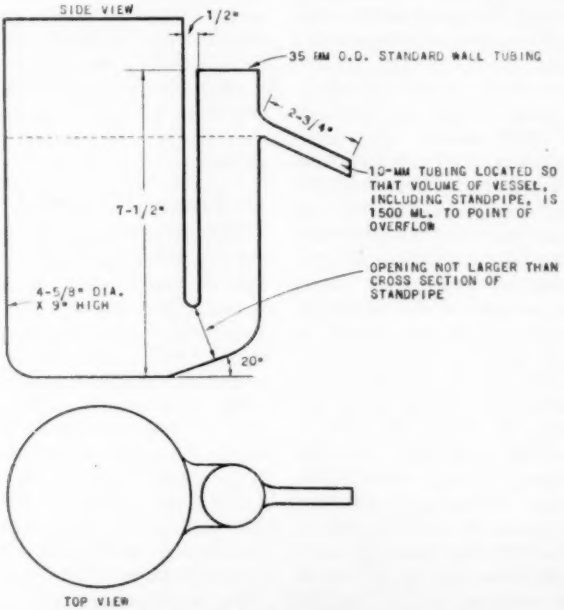
SIDE VIEW
1/2"
35 MM O.D. STANDARD WALL TUBING
2-3/4"
10-MM TUBING LOCATED SO THAT VOLUME OF VESSEL, INCLUDING STANDPIPE, IS 1500 ML. TO POINT OF OVERFLOW
7-1/2"
OPENING NOT LARGER THAN CROSS SECTION OF STANDPIPE
4-5/8" DIA. X 9" HIGH
20°
TOP VIEW

FIGURE 3.—Details of aerator-settler unit.

to 5-gal. bottles. Lines leading to and from the pump were made of 3/16-in. o.d. Saran tubing, the only rubber in the system being in the pump itself. Short stainless steel nipples served to join the Saran and rubber tubing. Air was delivered through a manifold at 4 p.s.i., and the air supply to each system was regulated by an individual needle valve.

Experimental Procedure

The treating systems were operated with continuous feeding 24 hr. per day, 7 days per week. Feeds were changed, all samples were taken, analyses were made, and changes in operating procedure were made between 8 A.M. and 4:30 P.M. on Monday through Friday. During the remainder of the time occasional checks were made to be sure that the systems were operating properly and to dispose of unwanted products.

Fresh samples of waste water were placed in the feed tanks each working day at 10 A.M. No precautions were taken to prevent exposure of waste water to the air because it was observed that oxidation of the pollutants during storage in contact with the air was very slow. Feed samples were analyzed immediately for permanganate oxygen consumed (O.C.), 5-day B.O.D., and phenols. Additional samples of feed were stored at 40° F. for preservation until the next day, when the remaining analyses were made along with all the analyses of the products. The product receivers were emptied and collection of fresh products was started around 2 to 4 A.M. each day. Around 9 to 11 A.M. the products accumulated since the 2 to 4 A.M. change were filtered through paper or decanted to remove the trace of sediment usually present. Throughout week-ends the systems operated on feeds which were fresh on Friday morning, and products were discarded until 2 to 4 A.M. Monday morning.

The temperature of the mixed liquor was normally maintained at 70 to 75° F.

The feed rates were adjusted to predetermined values within 0.1 ml. per minute. Pump rates usually remained constant from day to day to within a few tenths of a milliliter per minute. The range of values normally employed was 1.4 to 6.3 ml. per minute, corresponding to aeration periods of about 18 to 4 hr., respectively.

The air rate was approximately 0.1 cu. ft. per minute in almost all of the experiments. It was determined occasionally, but usually was estimated from appearance. The air diffusers were changed daily, as the porous glass tended to become plugged with slime. The slime was washed off with water, and the diffusers were cleaned and stored in concentrated nitric acid.

At times, suspended solids were found to build up in the settling section of some units. In such cases, the solids had to be flushed back into the aerator every 2 to 4 hr. with a portion of settled solution from the aerator. The amount which collected depended upon the condition and concentration of the growth and upon the turbulence pattern. The latter was influenced by the location of the air diffuser.

Source of Activated Sludge

The rate of growth of a floc fed with refinery waste water was much lower than that observed for a floc receiving domestic sewage. For this reason the development of a floc for treating refinery waste water was a prolonged procedure. Three sources of activated sludge were examined: (a) sludge developed from domestic sewage, (b) sludge developed from composited refinery waste water not containing domestic sewage, and (c) sludge developed from a single refinery waste-water discharge in which there was evidence of biological growth.

The most satisfactory procedure for producing activated sludge involved

aeration of domestic sewage for development of sufficient suspended solids followed by acclimatization of the microorganisms to the industrial waste by gradually increasing the ratio of industrial waste water to domestic sewage in the feed. Approximately one month was generally required for acclimatization of the sludge to refinery effluent. On only one occasion out of several, the microorganisms survived upon making a sudden change from domestic sewage to refinery effluent. During the early stage of acclimatization, prior to reaching a feed composed of equal amounts of industrial waste and domestic sewage, the condition of the sludge was judged from its appearance alone. Too rapid an increase in the relative amount of industrial waste usually resulted in a dense, pebble-like floc and a treated product with a stale odor. On some occasions the solids took on an opposite appearance; namely, very fluffy and not settleable. This type of sludge also gave a poor product.

Activated sludge was also developed by prolonged aeration of refinery waste water. Upon aeration of a spot sample of total refinery effluent for a few weeks, a suspension slowly formed which had the appearance of coarsely shredded tissue paper. The suspended solids settled rapidly to a fairly fluffy mass. Batch-wise feeding was carried out during the early development of the floc. Another floc developed from refinery effluent had the appearance of milkweed seed during the first week or two of its development. After about one month of continuous aeration and batch-wise feeding, a floc with normal appearance and performance was obtained in both cases.

A few unsuccessful attempts were made to develop a floc from a mixture of waste water and trench scrapings from a waste-water trench in which there was some biological growth. As there was no indication that a satisfactory floc was developing from this mixture after aeration for several days, the experiment was discontinued.

Properties of Suspended Solids

The condition of the floc was judged by (a) sludge volume index (S.V.I.), (b) rate of growth, (c) redox potential of the aerator mixed liquor, and (d) color. More reliance was placed on the first two criteria.

Sludge Volume Index

The Mohlman sludge volume index was chosen for the present work. It is defined as the volume, in milliliters, occupied by 1 g. of suspended solids after settling of mixed liquor for 30 min. In a plant-scale treatment unit a 1,000-ml. sample is prescribed for this analysis, but in view of the practical limitations of size in a bench-scale unit a 100-ml. sample was normally used. The settled volume was about twenty per cent greater with the 100-ml. sample. For example, if a 1,000-ml. sample of mixed liquor yielded 20 per cent by volume of settled solids, a 100-ml. sample of the same slurry would yield 24 per cent by volume of settled solids. A S.V.I. of 50 to 125 ml. per gram was considered satisfactory. Values higher than 125 were observed during periods characterized by overloading and/or low pH. None of the other intentional maltreatments of the sludge resulted in bulking, although there were indications that extension of certain maltreatment periods might have caused bulking.

For the purpose of determining the S.V.I. it was found that a correlation curve could be constructed from which the dry weight of the suspended solids could be predicted with fair accuracy from the volume of solids settled by centrifugation. Calculation of the approximate S.V.I. from the dry weight estimated in this manner, together with the volume settled upon standing for 30 min., gave results which agreed within $\pm$ 10 ml. per gram of the S.V.I. obtained by actually determining the

dry weight of suspended solids. This shortened procedure was not used in the current work, but it would be largely used in any future study.

Rate of Growth

The rate of growth of a floc fed with refinery waste water was usually about four per cent per day, about one-twelfth the rate reported for some systems operating with domestic sewage. This slow rate of multiplication was principally responsible for the extended period required for development of a satisfactory floc during start-up of a unit. Three qualitative observations relating to the rate of growth were made: (a) the rate of growth increased with an increase in loading; (b) floc disappeared from a system which was underloaded, appearing as a colloidal dispersion in the product water; and (c) it was possible for a system to operate satisfactorily for a few days without sludge removal and yet with little increase in sludge content of the aerator, the rates of growth and deterioration apparently being equal and small.

Redox Potential

The use of the redox potential for determining the condition of suspended solids in the treatment of domestic sewage is described in the literature (2)(3). In brief, the method involves determination of the electrode potential of a platinum electrode, referred to some standard such as the saturated calomel electrode, after the platinum electrode has been immersed in either the feed, mixed liquor, or product for a fixed interval of time, usually 15 min. Immediate repeat determinations of the potential difference with a given sample usually revealed a repeatability of $\pm$ 0.02v. On several occasions much poorer repeatability was observed without apparent reason so that, in view of the analytical limitations, significance was attached only to the major trends observed.

It was observed, as expected, that the electrode potential of the product was normally more positive than that of the feed. It was observed that the potential of untreated refinery effluent was normally between $\pm$ 0.00 v. and $-$ 0.10 v. when compared with the saturated calomel electrode, and that variation in the potential of the feed caused similar variations in the potential of mixed liquor and product. In view of the fact that apparently normal suspended solids and a satisfactory treatment were maintained over wide limits of the electrode potential of the product, it was not possible to choose some standard potential as a guide for determining suitable operating conditions. Upon treating a feed as varied in composition as refinery effluent, it appeared that the only significant factor was the difference between the potential of the mixed liquor and that of the feed at a given time. A positive value of this difference was considered as an indication that the floc was in good condition.

Periods during which the potential of the mixed liquor was less than that of the feed usually corresponded to periods of abnormal and presumably unsatisfactory treating conditions, although treating efficiency was not always impaired. The following causes of deteriorating floc and unsatisfactory treating conditions, as judged by potential measurements, were detected:

1. High phenol concentration.
2. Overloading.
3. Underloading.
4. Insufficient air and/or mixing.

It was interesting to find that potential measurements failed to indicate that a low pH was undesirable, even though bulking and decreased treating effectiveness resulted at low pH.

Ammonia and Phosphate Requirement

In order for the microorganisms in activated sludge to grow and maintain

satisfactory health and activity, it is known that sufficient amounts of inorganic as well as organic nutrients must be present in the waste water undergoing treatment. In order to obtain the most effective removal of those pollutants which are mainly responsible for the B.O.D. and O.C. (that is, organic nutrients), other workers have shown that a proper balance must exist between the concentration of organic nutrients and soluble inorganic salts containing nitrogen and phosphorus (4)(5). Very little work has been reported concerning the requirements for additional inorganic nutrients, but it is known that at least trace amounts of other salts are needed. The waste water in this work usually contained 20 to 30 p.p.m. of ammonia nitrogen, 30 to 40 p.p.m. total nitrogen, and 30 p.p.m. soluble phosphate, and, as mentioned previously, the B.O.D. averaged 1,100 p.p.m.

It was unexpectedly found that there was no significant correlation between B.O.D. (or O.C.) disappearance and nitrogen and phosphorus disappearance. It was likewise found that no significant correlation existed between the rate of increase of suspended solids and utilization of nitrogen and phosphorus, but it is considered likely that the lack of correlation was attributable

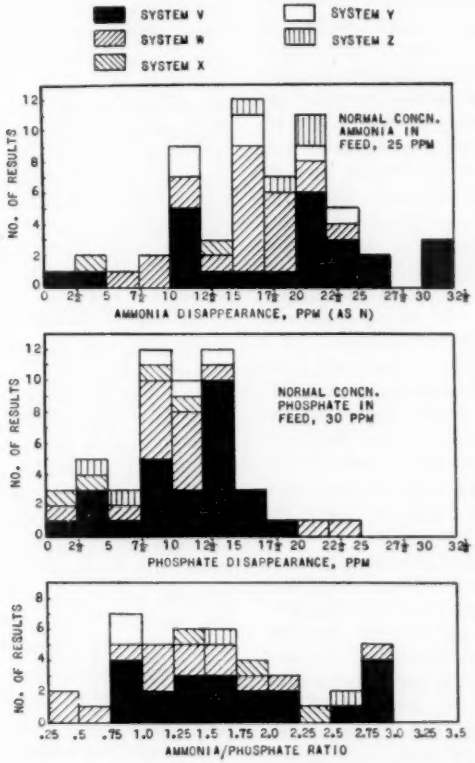

FIGURE 4.—Disappearance of ammonia nitrogen and soluble phosphate during treatment with activated sludge.

to the fact that the experiments were not designed to study these relationships. In view of the evident limitations with regard to the establishment of nutritional requirements, the data shown in Figure 4 were collected over an extended period and plotted in a fashion to indicate the ammonia and phosphate disappearance and the ratio of ammonia disappearance to phosphate disappearance without regard to the concentration of pollutants in the effluent and the treating conditions. It can be seen that the disappearance of ammonia nitrogen and soluble phosphate was usually about 15 to 23 p.p.m. and 8 to 15 p.p.m., respectively. The loss of ammonia by stripping during aeration was not corrected for, but it was found to be generally less than 1 p.p.m.

Examination of data concerning the disappearance of ammonia and total nitrogen (exclusive of nitrate-nitrite) upon treatment of more than 50 samples of waste water revealed that reduced-nitrogen compounds other than ammonia, such as amines, were not appreciably utilized by the microorganisms. In 42 instances the disappearance of total nitrogen could be accounted for by the disappearance of ammonia to within an average of $\pm$ 3 p.p.m. as nitrogen. Normally, the concentration of ammonia present in the waste water was 6 p.p.m. greater than that required by the floc, and presumably there was no need for the organisms to utilize other more difficultly assimilable nitrogen bases.

In addition to assimilation of nitrogen in the form of ammonia, it appeared that nitrate and nitrite nitrogen were also used by the microorganisms. It was unexpectedly observed that the concentrations of nitrite and nitrate in the normal waste water were both lowered during treatment in all but one of more than 25 instances. Treatment of a synthetic waste water, which was supposed to have approximately the same gross composition as the normal waste water, resulted in an increased concentration of nitrite and a lowered concentration of nitrate (Table I).

TABLE I.—Effect of Treatment with Activated Sludge on Nitrate and Nitrite Nitrogen

Sample	Nitrite (p.p.m.)	Nitrate (p.p.m.)
Normal waste water:		
Feed	0.3	4.5
Product	0.2	1.4
Syn. waste water:		
Feed	0.1	15.4
Product	0.8	1.3

Because the process was aerobic, it was not considered likely that reduction of nitrate and nitrite by the microorganisms would take place, particularly since the requirement of ammonia was apparently satisfied by ammonia in the feed. Apparently both nitrite and nitrate could be utilized as such by the microorganisms. Although no study was carried out to examine the effect of the presence of nitrate and nitrite upon treatment effectiveness, no difficulties were ever definitely traced to the presence of too large an amount of either nitrite or nitrate.

Effect of Waste Composition

As study of each of the numerous factors influencing treatment of refinery effluent would be too time consuming if each of the experiments was carefully controlled, compromises were made in the present experiments in order to obtain satisfactory indications of the effect of variables in a reasonable period. Treatments were usually made simultaneously in six separate systems, and experiments with each of the systems were carried out consecutively. As described earlier, a given waste water was normally used for 24 hr., and no further attempt was made to achieve a steady-state condition between the suspended microorganisms and their environment. It is evident, therefore, that the past history

of the sludge would influence the treating efficiency in a given experiment, and that this effect could be only partially accounted for. The influence of unknown variation in the composition of the daily samples of waste water was largely overcome by feeding essentially the same waste water to each of the systems simultaneously, and in general only one condition in each system was changed at one time. One system, the control, was maintained at optimum conditions. Average results over the period of examining the influence of a given condition were considered to be valid indications of the results which would have been obtained in a more carefully controlled system, and the results very likely show more clearly what might happen in a commercial plant.

Loading

A system was considered to be properly loaded when the most effective treatment was continuously obtained and optimum characteristics of the suspended solids were maintained. When the suspended solids deteriorated and the treatment was impaired, a system was considered to be either overloaded or underloaded unless the difficulty was definitely traceable to some other cause.

Among the several dimensionally equivalent relationships useful for expressing the loading of a system, the one used was pounds of pollutant per day in the feed per pound of suspended solids in the aerator. Although loading obviously could be expressed in terms of any pollutants, loadings expressed in terms of B.O.D., O.C., or phenols would be only roughly proportional when applied to a waste as variable in composition as refinery effluent. For example, the B.O.D./O.C. ratio of different samples of waste water was found to vary from 0.75 to 4.0. Variations in the types of pollutants in the waste water, as revealed by different B.O.D./O.C. ratios, tend to limit the importance of the loading value as a treating parameter. To illustrate, it is likely that a floc acclimated to a high concentration of ketones would deteriorate if suddenly deprived of ketones, even if different organic substances were substituted to maintain a constant total B.O.D. In spite of the shortcomings of the loading value as a treating parameter, over-all loading was considered to be an important variable influencing the effectiveness of treatment with activated sludge.

The three factors contributing to loading are:

1. Concentration of pollutants in feed.
2. Concentration of suspended solids.
3. Aeration period.

TABLE II.—Effect of Loading on Effectiveness of Treatment

Exp. No.	Test Period (days)	Susp. Solids (p.p.m.)	Aeration Period (hr.)	Loading (lb./day/lb. sludge)			Removal (%)		
				B.O.D.	O.C.	Phenols	B.O.D.	O.C.	Phenols
a	24	5000	12	0.44	0.23	0.048	92	75	94
b	5	7700	4	1.14	0.31	0.074	87	60	90
c	4	6700[1]	4.5	—	0.39	0.065	—	75	93
d	4	3800[1]	9	—	0.35	0.058	—	71	93
e	10	4100[2]	12	0.71	0.22	0.054	89	56	92
f	10	6350[2]	12	0.46	0.14	0.035	93	67	93

[1] Experiments c and d were carried out in parallel, using the same feed for each system, and using portions of the same composited floc in each aerator.

[2] Experiments e and f were carried out in parallel, using the same feed for each system. The suspended solids had slightly different histories.

No effort was made to control the concentration of pollutants in the feed, various samples of waste waters being used without major adjustment of pollutant concentration. Control was exercised over the concentration of suspended solids in the aerator and the aeration period in order to obtain the loading desired for any particular experiment. The results of experiments illustrating the effect of loading on the operation of a unit are summarized in Table II.

The data in Table II reveal that the average removal of B.O.D. decreased from 93 to 87 per cent upon increasing the B.O.D. loading over the range examined (0.45 to 1.14 lb. B.O.D. per day per pound of sludge). The data also show that phenols removal was not significantly influenced by loading over the range of loadings examined. Although the data concerning loading with O.C. reveal much less over-all agreement, some valid conclusions regarding removal of O.C. could be drawn from the above results. Experiment a gave results which represented closely the results obtainable in a properly operated system. Results similar to those of experiment a were obtained on numerous occasions, and should be easily achieved in a unit operated for maximum treatment. Experiment b revealed that a two-to-three-fold increase in the over-all loading of a system which had been operating satisfactorily would cause fairly rapid impairment of treating effectiveness. Experiments c and d demonstrated that the same treatment of identical feeds with different portions of identical suspended solids was obtained when the concentration of suspended solids and the aeration period were mutually complementary over the range of values investigated. Experiments e and f revealed an unusually low removal of O.C. in each of the systems. The unsatisfactory removal of O.C. in experiment e may have resulted in part from overloading of the

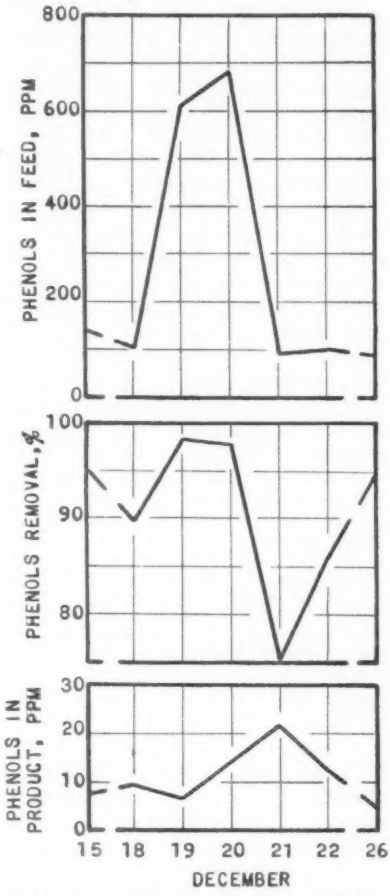

FIGURE 5.—Effect of shock overloading with phenols.

system with phenols for the week preceding this experiment, although during the period of overloading with phenols no significant effect on removal of O.C. was noticed. The low removal of O.C. by the system with the higher concentration of suspended solids (experiment f) may have been partly the result of underloading, resulting in sloughing off of deteriorated sludge, which remained colloidally dispersed in the product and imparted a high O.C. to the treated water.

Phenols

Data concerning the removal of phenols during a two-day period of treating waste water having excessive phenols are given in Figure 5. The system had been operating satisfactorily with normal waste water before a sudden, six-fold increase in the concentration of phenols occurred. It can be seen in Figure 5 that there was a lag between the onset of overloading and an increase in the concentration of phenols in the treated product. The concentration of phenols in the treated product remained abnormally high until the third day after cessation of shock overloading. The removal of B.O.D. and O.C. was affected in essentially the same manner by the increase in concentration of phenols in the effluent. This experiment led to the conclusion that the main effect of an abrupt increase in phenols for one to two days was a temporarily higher concentration of pollutants in the treated products. The data given in Table II, experiment e, indicate that the excessive phenols may have caused a slight amount of lasting damage to the floc.

Figure 6 shows the effect of a more gradual increase in the loading of phenols over a period of 10 days. It can be seen that the maximum increase of 160 per cent in the concentration of phenols in the bio-treater feed to system A resulted in a corresponding 38 per cent increase in the concentration of phenols in the treated water. Average removal of phenols in the high-phenols system (system A) was about 97 per cent, compared to about 94 per cent removal in the normal control system (system B). It was concluded that an activated sludge unit operated normally on about 100 p.p.m. phenols in the feed can be satisfactorily acclimated to a feed with 350 p.p.m. phenols in an interval as short as one week.

The color of the treated product was normally light yellow or light orange during periods of treating waste containing about 100 p.p.m. phenols. It was observed that the intensity of the color increased somewhat with an increase in the concentration of phenols, thus indicating that the color was largely attributable to the oxidation products of phenols. Various attempts to obtain a substantially colorless product were not successful.

Acidity

The effect of lowering the pH of the waste water from 8 to 6 was determined during a period of overloading with phenols. The data for a system with feed adjusted to pH 6 (system C), and a control system at pH 8 (system D) are plotted in Figure 7. Except for

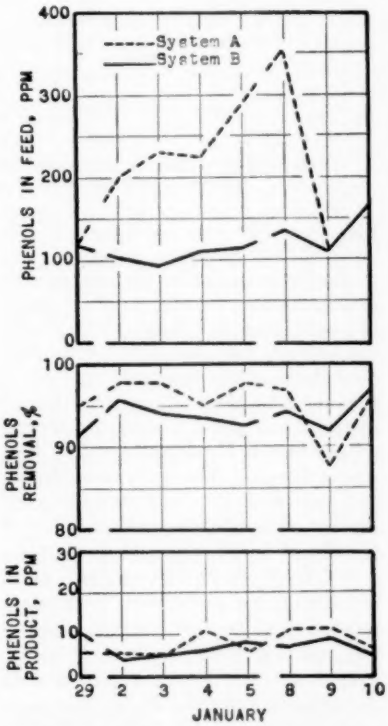

FIGURE 6.—Effect of slow increase in concentration of phenols.

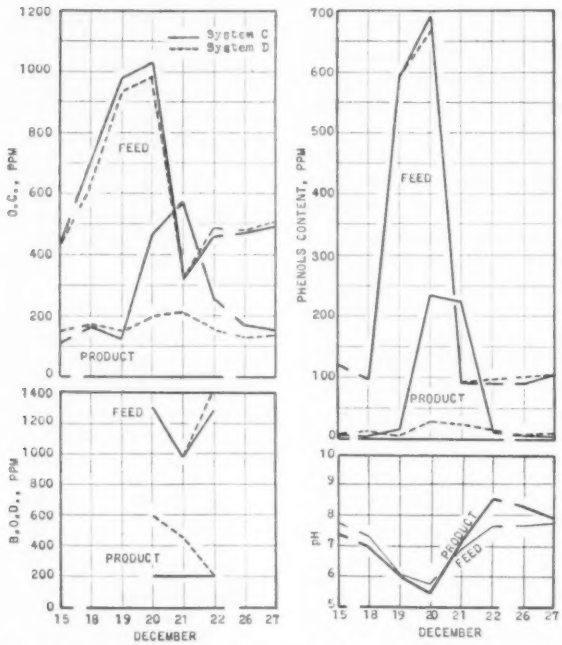

FIGURE 7.—Effect of increased acidity at time of overloading with phenols. System C, pH less than 8; system D, pH maintained at 8.

pH, the feeds were identical. It can be seen that treatment efficiency was markedly impaired in the system with greater acidity during shock overloading with phenols. Removal of B.O.D. and phenols was normal two days after discontinuing the feed with the lowest pH and the highest concentration of phenols, but about six days were required before normal removal of O.C. was attained. The most undesirable and lasting effect of simultaneous overloading with phenols and acidification of effluent was bulking of the sludge, a S.V.I. of about 200 ml. per gram remaining for about one week after returning to feed of normal composition and lengthening the aeration period to 18 hr. During this period of operation with bulked sludge, the treatment efficiency was not significantly lowered but separation of sludge from the product was obviously less satisfactory.

The effect of increasing the acidity of a waste water having otherwise normal composition was also examined. No rigid control was used in this experiment, but the removal of O.C. appeared to be somewhat impaired at

TABLE III.—Activated Sludge Treatment of Waste Water at pH 10

	Min.	Max.	Av.
Composition of feed:			
pH	9.8	10.1	9.9
O.C. (p.p.m.)	280	970	510
Phenols (p.p.m.)	65	135	95
Conditions of treatment:			
Aeration (hr.)	—	—	9
Susp. sol. (p.p.m.)	3,550	6,150	4,400
Effectiveness of treatment:			
O.C. removal (%)	63	84	77
Phenols rem. (%)	89	96	93

TABLE IV.—Activated Sludge Treatment of Waste Water with a High Salt Content

	Experiments with Added Salts			Experiments with Normal Salt Level		
	Min.	Max.	Av.	Min.	Max.	Av.
Composition of feed:						
Diss. inorg. sol. (p.p.m.)	4,798	8,343	6,250	3,200	4,300	3,780
B.O.D. (p.p.m.)	990	1,510	1,340	990	1,450	1,250
O.C. (p.p.m.)	320	1,200	580	320	980	575
Phenols (p.p.m.)	90	720	205	75	690	210
Conditions of treatment:						
Aeration (hr.)			12			12
Susp. sol. (p.p.m.)	3,200	7,000	4,500	4,150	6,150	5,000
Effectiveness of treatment:						
B.O.D. removal (%)	77	93	86	79	94	85
O.C. removal (%)	67	84	75	67	84	74
Phenols removal (%)	79	97	93	76	99	93

pH 6, judging from the O.C. of products prior to and during the experiment. The main observation was that the sludge bulked with feed having pH 6 even though no other abnormal qualities of the feed were noted. It was obvious, therefore, that a decrease in pH from an accustomed value of about 8 to about 6 over a period of four days was detrimental. It was not determined whether or not the floc could be eventually acclimated to an environment with pH 6.

Alkalinity

The effect of increasing the alkalinity of the waste water from pH 8 to pH 9.5 to 10 was examined. A system was acclimatized to a waste water with pH 10 by a gradual increase in pH over a period of four days. During this period, treatment efficiency was poor, due to an earlier experiment in which air was introduced into the aerator at a decreased rate. For the week following acclimatization of the floc, effluent having a pH of about 10 was treated and the degree of purification was equal to the optimum treatment obtained with a waste having pH 8. Furthermore, the sludge exhibited no signs whatsoever of deterioration. The data obtained are summarized in Table III.

On one other occasion a system was operated satisfactorily for 10 days when the pH of the mixed liquor was 8.5 to 9.5.

Salt Content

Treatment of normal waste water with an average inorganic salt content of about 3,500 p.p.m. was compared with treatment of waste waters having an enhanced content of inorganic salts. The concentration of salts was increased daily by equal increments over a period of one week, using two parts of sodium sulfate to one part of sodium chloride, until the total concentration of inorganic salts in the waste water fed to the treatment unit reached a maximum of 8,300 p.p.m. After two days the concentration of salts was decreased gradually to the normal level over a period of one week. The data shown in Table IV indicate that operation with a salt content in the range studied was satisfactory. There was an indication that the microorganisms in the system with an increased concentration of salts did not recover from overloading with phenols as rapidly as did a normal system, but this effect was slight. The floc became more dense as the concentration of salts in the feed increased, presumably from dehydration.

Sulfide Content

The presence of up to 8 p.p.m. sulfide did not affect the removal of phe-

TABLE V.—Effect of Sulfide on Efficiency of Activated Sludge Treatment

	1st-3rd Day	6th Day
Composition of feed:		
Sulfide (p.p.m.)[1]	1–3	8
B.O.D. (p.p.m.)	710–1,060	—
O.C. (p.p.m.)	320–415	390
Phenols (p.p.m.)	53–82	27
Conditions of treatment:		
Aeration (hr.)	12	12
Susp. sol. (p.p.m.)	4,200	4,200
Effectiveness of treatment:		
Sulfide removal (%)	100	100
B.O.D. removal (%)	95	—
O.C. removal (%)	61	42
Corr. for S =	58	29
Phenols removal (%)	93	80

[1] The concentration of sulfide was increased on successive days as follows: 1st day, 1 p.p.m.; 2nd day, 1.5 p.p.m.; 3rd day to 5th day, 3 p.p.m.; 6th day, 8 p.p.m.

nols from waste water, but the removal of O.C. was markedly impaired, as shown in Table V. The presence of up to 3 p.p.m. sulfide for a period of three days did not influence the removal of B.O.D. The removal of B.O.D. at a higher concentration of sulfide was not determined, but, judging from removal of O.C., a higher concentration of sulfide would have been detrimental. Satisfactory treating efficiency rapidly returned upon cessation of sulfide addition, indicating that the presence of sulfide for about one week caused no lasting impairment of treatment efficiency.

"Oil"

In view of the fact that hydrocarbons and additional substances which separate from the waste water are normally removed in oil separator boxes in the refinery, any such material which separated from the samples of waste water was skimmed off and not fed to the bio-treatment unit. The concentration of finely dispersed and dissolved "oil," according to the U-tube method, in the waste water fed to the treatment units was usually about 25 p.p.m. Because satisfactory treatment was obtained when attempts were made to maintain satisfactory operating conditions regardless of the oil content of the water, it was concluded that the presence of 25 p.p.m. of dissolved oil in the waste water was not detrimental. The effect of a greater concentration of oil was not ascertained.

Effect of Operating Variations

Air Rate

The air rate employed in the operation of a bench-scale unit was about 0.10 cu. ft. per min., an amount corresponding to about 0.9 cu. ft. per min. per square foot of aerator surface. This quantity of air is about 400 times greater than that required for complete reaction with 1,000 p.p.m. B.O.D. The high air rate in a bench-scale unit is necessitated by the inefficient absorption of oxygen by the mixed liquor due to the short contact time between the air and the solution. Furthermore, sufficient air must be used to insure adequate mixing of the mixed liquor. The air rate expressed in terms of cubic feet per minute per square foot of aerator surface is comparable to that used in some activated sludge plants.

A study was made to determine the effect of the air rate on the efficiency of treatment in a bench-scale unit. It was found that an air rate of 0.06 cu. ft. per min. resulted in satisfactory removal of B.O.D. and phenols, but lowered removal of O.C. Further reduction of the air rate to 0.01 cu. ft. per min. severely retarded the removal of all contaminants. After two days of operation with the lowest air rate, the removal of B.O.D., O.C., and phenols had decreased to 59, 34, and 70 per cent, respectively, compared with removal in the control system of 91 per cent B.O.D., 78 per cent O.C., and 92 per cent phenols. Upon resumption of normal air rate, high efficiency of treatment was rapidly restored and there appeared to be no lasting impairment of the activated sludge.

Inasmuch as an air rate of a few hundredths of a cubic foot per minute was at least a 100-fold excess over the

theoretical requirement for air, it appeared that the lack of sufficient mixing was an important reason for decreased treating effectiveness with decreased air rate, although the amount of air used apparently furnished sufficient agitation. The effect of lowered air rate with simultaneous mechanical mixing was therefore examined. The aeration tank liquor was mechanically swirled with a cylindrical stirrer having dimensions of 7/8-in. diameter by 4.5-in. length, and rotated on its axis at 700 r.p.m. It was found that the removal of O.C. in the unit operated with an air rate of 0.035 to 0.05 cu. ft. per min. and with mechanical mixing was generally about 5 per cent greater than the removal of O.C. in a normally operated unit. This presumably resulted from better contact of the air and water and also possibly from the presence of a smaller amount of colloidally dispersed sludge in the product from the mechanically mixed system. The removal of phenols was 92 per cent in each unit. Furthermore, there was no indication of sludge deterioration in the system operating with reduced air.

Pre-Aeration

The utility of aeration of the waste water prior to treatment with activated sludge was examined. It was found that there was appreciable over-all purification of refinery effluent by aeration for either 6 or 12 hr., the removal of O.C., B.O.D., and phenols being about 40, 50, and 85 per cent, respectively, of the removal obtained in the presence of activated sludge. The possibility that there was significant removal of O.C. and phenols by evaporation into the air stream was not studied, but loss in this fashion does not appear likely, as work described later showed that essentially no stripping by air occurred in a normal biological treatment unit. Results of two aeration experiments, each lasting one week, are summarized in Table VI.

Treated water was recycled from a bio-treatment unit to an aerator to determine whether or not there were an advantage to be gained from the possible presence of enzymes in the recycle stream. At a constant feed rate of waste water, it was found that the recycle of one volume of product from a bio-treatment unit for every two volumes of waste water actually caused a significant decrease in the rate of removal of pollutants in the aerator.

Bio-Treatment Following Pre-Aeration

For a period of about one month, refinery waste water was treated in a two-stage system comprising a pre-aerator and a biological treatment unit, the two stages having equal capacity. A control, single-stage biological treatment unit was also operated during the first half of this period, the same waste water being used as feed to both systems. The data summarized in

TABLE VI.—Aeration in the Absence of Activated Sludge

	Experiment A			Experiment B		
	Min.	Max.	Av.	Min.	Max.	Av.
Composition of feed:						
B.O.D. (p.p.m.)	1,120	1,450	1,300	1,270	1,370	1,300
O.C. (p.p.m.)	430	620	500	370	520	435
Phenols (p.p.m.)	75	165	125	80	160	110
Aeration (hr.)	—	—	12	—	—	6
Effectiveness of treatment:						
B.O.D. removal (%)	48	48	48	38	50	44
O.C. removal (%)	24	46	32	14	41	27
Phenols removal (%)	71	89	77	77	85	82

Table VII show that normal treatment with activated sludge at 12-hr. detention resulted in somewhat greater removal of O.C. than did pre-aeration for 6 hr. followed by 6 hr. of treatment with activated sludge. Removal of phenols was the same in both instances, but removal of B.O.D. was slightly less effective in the system with pre-aeration. This result would indicate that the total detention time (total capacity divided by feed rate) in a two-stage system with equal periods of pre-aeration and bio-treatment would have to be slightly larger than the retention time in a one-stage bio-treatment unit in order to get equal treatment, provided the concentration of suspended solids were the same in the two bio-treatment units.

The optimum portion of the over-all detention time allocated to the pre-aeration is, of course, not necessarily 50 per cent. It is quite possible that by suitable adjustment of detention times and suspended solids concentration fully equivalent results might be observed from the combination of pre-aerator and bio-treatment unit. Moreover, the pre-aerator helps to stabilize conditions in the bio-treatment unit and to prevent shock loading. The sludge volume index and other properties of the floc in the two-stage system were consistently more satisfactory than those of the floc in the single-stage system, in spite of the slightly poorer treatment obtained.

Two-Stage Bio-Treatment

Data were gathered which showed fairly conclusively that two-stage biological treatment offered no significant advantage over one-stage treatment or pre-aeration followed by bio-treatment. Pre-aeration accomplished substantially the same result as first-stage bio-treatment and the danger of shock overloading the first stage was avoided. Two-stage bio-treatment required more careful control than single-stage treatment because it was difficult to maintain a satisfactory environment for the microorganisms in both stages simultaneously.

Clarification of Treated Product

It was occasionally observed that removal of O.C. and turbidity was poor, but removal of B.O.D. and phenols was good. Impaired treatment of this type was believed to result from rapid variations in over-all loading and rapid changes in the types of substances responsible for contamination. During periods characterized by this type of

TABLE VII.—Pre-Aeration Followed by Bio-Treatment *vs.* Single-Stage Bio-Treatment

	Pre-Aeration Followed by Bio-Treatment			Single-Stage Bio-Treatment		
	Min.	Max.	Av.	Min.	Max.	Av.
Composition of feed:						
B.O.D. (p.p.m.)	670	1,460	1,110	670	1,320	960
O.C. (p.p.m.)	300	1,060	530	320	1,060	610
Phenols (p.p.m.)	50	290	105	90	170	115
Conditions of Treatment:						
Aeration period (hr.):						
Pre-aeration	—	—	6	—	—	0
Bio-treatment	—	—	6	—	—	12
Susp. solids (p.p.m.)	3,700	5,900	5,055	3,900	6,100	5,115
Effectiveness of treatment:						
B.O.D. removal (%)	87	99	92	84	99	95
O.C. removal (%)	33	85	66	67	90	77
Phenols removal (%)	84	97	93	86	98	93

TABLE VIII.—Stripping of Pollutants from Effluent Water during Treatment

Effl. Vol. (l.)	Air Vol. Used (cu. ft.)	Absorber Solution	Pollutants Collected in Absorber (p.p.m.)[1]		
			Phenol	O.C.	Ammonia
3	60	tap water	0.0	—	0.4
2.9	91	tap water	0.0	0.5	0.0
2.9	81	0.1 N HCl	0.0	0.5	0.3
2.5	101	0.1 N HCl	—	0.0	1.9
2.6	158	0.1 N NaOH	0.0	0.7	—
2.5	187	0.1 N NaOH	0.0	0.1	—

[1] On basis of effluent.

treatment, the removal of turbidity from the treated products by clarification with 200 p.p.m. aluminum sulfate also resulted in a significant decrease in O.C. It was found that the decrease in O.C., relative to the decrease in turbidity, became greater as the O.C. of the unclarified product increased. It was thus indicated that colloidally dispersed, deteriorated floc in a treated product could be responsible in part for high O.C. at times when satisfactory removal of phenols and B.O.D. was obtained. This explanation was strengthened by the fact that feeding of tap water for two days to a treatment unit which had been previously overloaded resulted in a product with the following properties: B.O.D., 2 p.p.m.; phenols, 0 p.p.m.; O.C., 145 p.p.m.; and turbidity equivalent to 30 p.p.m. sodium silicate.

Effect of Silicone Antifoam

The waste water usually contained substances such as soaps and sulfonates, which caused appreciable foaming (frothing) in the aerator. Frothing was undesirable because the air rate had to be lowered to prevent loss of aerator liquor and because flotation caused sludge to be deposited on the sides of the aerator out of contact with the mixed liquor. It was found that the addition of 0.05 ml. of Dow Corning Antifoam A every 4 hr. was quite effective for reducing foaming. On occasion, severe foaming of effluent occurred and a larger-than-normal rate of addition of silicone was required. The poor treating efficiency sometimes obtained during the periods of high foaming apparently resulted from the presence of relatively stable pollutants, which were possibly responsible for the marked frothing. Under normal conditions it was found that the treating efficiency was not influenced by the Antifoam, even when the rate of addition was 20 times greater than normal.

Properties of Effluent Air from Treatment Unit

In view of the fact that a large volume of air would be discharged to the atmosphere after passage through a plant-scale treatment unit, the possibility of air pollution resulting from aeration of refinery waste water was considered. As shown in Table VIII, the amount of pollutants stripped from the waste water during treatment was slight.

It can be seen that phenols were not stripped from the aerator by air during treatment. It does not appear that the very small contribution to the atmosphere of ammonia and substances responsible for O.C. in the waste water would constitute a valid objection to plant-scale treatment with activated sludge. The effluent air had a mild musty or earthy odor, which was not unpleasant to laboratory personnel and which was similar to that observed in treatment of domestic sewage.

Conclusions

A bench-scale method for continuous activated sludge treatment was devised and successfully employed in the laboratory treatment of waste water from a petroleum refinery. The following conclusions were drawn from the observations made:

1. About 9 to 12 hr. of aeration in the presence of 4,000 to 5,000 p.p.m. suspended solids normally resulted in 90 to 95 per cent removal of 5-day B.O.D., 70 to 75 per cent removal of permanganate oxygen consumed (O.C.), and 90 to 95 per cent removal of phenols from waste water with an average composition of 1,100 p.p.m. B.O.D., 500 p.p.m. O.C., and 100 p.p.m. phenols. Optimum loading was about 140 lb. of B.O.D. per day per 1,000 cu. ft. of aeration space, or about 0.5 lb. B.O.D. per day per pound of suspended solids. The treated product was usually light yellow and had a musty or earthy odor which was judged not unpleasant.

2. The rate of growth of floc fed with refinery waste water was about 4 per cent per day, so that a relatively prolonged period was required to develop the floc; the rate of disposal of excess suspended solids was low.

3. The disappearance of ammonia nitrogen and phosphate during treatment was roughly 19 p.p.m. and 11 p.p.m., respectively. If these amounts, at least, are present in the water to be treated, no added inorganic nutrients should be required.

4. The main effect of a sudden increase in phenols concentration from 100 to 600 p.p.m. was a temporary decrease in treatment effectiveness. Increase in the phenols concentration from 100 to 350 p.p.m. in an interval of one week resulted in satisfactory acclimatization of the activated sludge to the higher concentration of phenols.

5. Decrease in the pH of the feed from a normal value of 8 to a value of 6 over a period of four days was detrimental. Increase in the pH to a value of 10 over a period of four days resulted in satisfactory acclimatization of the floc to the higher pH.

6. Increase in the concentration of inorganic salts from the normal value of 3,500 p.p.m. to a value of about 8,300 p.p.m. in an interval of one week caused no adverse effects.

7. The presence of 1 to 3 p.p.m. of sulfide for three days caused only slight impairment of the treatment efficiency. The presence of 1 to 8 p.p.m. of sulfide for six days caused greater impairment of the treatment efficiency. The presence of up to 24 p.p.m. sulfide for one day was not detrimental.

8. Aeration of the waste water prior to activated sludge treatment helped significantly in the stabilization of conditions in the bio-treatment unit and tended to reduce the chances of shock loading. Total treatment unit capacity (pre-aerator plus bio-treatment unit) would probably not have to be larger than the capacity of an equivalent single-stage bio-treatment unit.

9. Two-stage biological treatment offered no significant advantage over one-stage treatment or pre-aeration followed by bio-treatment.

10. The amount of pollutants stripped by the air from an aerator was so small that pollution of the air should not constitute a valid objection to activated sludge treatment.

Acknowledgments

The author wishes to acknowledge the excellent assistance of S. York, who did much of the laboratory work; P. D. Crebbin, who prepared and analyzed many of the samples; and R. A. Bannerot, who offered numerous valuable suggestions and criticisms.

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CITIES ISSUE MORE REVENUE BONDS

Cities are making wider use of revenue bonds as a means of financing revenue-producing facilities.

In a survey made early this year for the "1952 Municipal Yearbook," published by the International City Managers' Association, 205 cities of more than 10,000 population reported issuing $287,084,875 in revenue bonds during 1950–51—or nearly 22 per cent of all revenue bonds reported by *The Bond Buyer* as being sold during the two-year period by states, local authorities, and other local jurisdictions. Principal and interest of these bonds are paid solely from earnings of the facility financed by the bond proceeds.

In order of volume of sales, revenue bonds were sold most frequently by cities for water, electric, sewer, parking, and airport facilities. Considered from the standpoint of the number of cities selling revenue bonds, these same five purposes led the field with a slight change in the order: water, sewer, parking, electric, and airport facilities.

CHEMICAL OXIDATION OF PHENOLIC WASTES WITH CHLORINE *

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Industries contributing phenolic wastes to surface water may be divided into two classes—industries that produce phenols or allied compounds and industries that use phenols or allied compounds. Producers include coke plants, gas plants, dye manufacturing plants, wood distillation plants, and certain chemical plants. Users include manufacturers of phenolic plastics, synthetic resins, reclaimed rubber, antiseptics, and explosives.

The presence of phenols or phenolic compounds in drinking water supplies is a nuisance because, when chlorinated, unpleasant and persistent tastes and odors are produced. These tastes and odors are probably due to the formation of mixtures of o-chlorophenol, p-chlorophenol and tri-chlorophenol. The presence of very small amounts of these compounds, in some instances as little as 0.1 p.p.b., can be readily detected.

Combinations of chlorine with the higher phenolic compounds more complex than phenol itself normally produce chloro derivatives. These compounds give rise to tastes and odors also, but considerably higher concentrations can be tolerated. Thus, even small amounts of various phenolic compounds discharged from a multiplicity of manufacturing plants may build up in a stream to the point where they will give trouble.

In addition to the effect on drinking water supplies, their presence can be detrimental to certain industries, such as, for example, in the manufacture of paper food containers. Here the phenolic compounds are held in the fibers, from which the tastes and odors pass into the food upon storage. While on the subject of food, it is of interest to note that fish may not avoid unnatural pollution such as phenols. If the fish are not killed by the phenol content of the stream, those caught for edible purposes may have a phenolic flavor.

There is considerable evidence showing that phenolic compounds tend to be oxidized progressively with time in the receiving stream. The loss is due primarily, according to Ettinger and Ruchhoft (1), to biochemical action. However, they feel that such action cannot always be depended upon because the "rates of removal of these materials are governed by the factors that control the metabolism of the microbiological agencies involved" and that "the exact course which the removal of the phenolic compound will follow cannot be accurately predicted."

It has long been evident, even prior to the work mentioned, that control or correction of phenol pollution at the source would be necessary. During the 1920's such control took the form of river patrols to prevent or at least report spills of gross quantities of phenols. This was only partially successful. Corrective measures of water treatment plants include the use of activated carbon and the ammonia-chlorine process. These measures, likewise, were only partially successful. Dur-

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ing the past few years the use of chlorine dioxide at water plants has proven quite effective as a corrective agent.

Even with strict river patrols and improved corrective measures, the phenol problem has never been completely solved. This has led to the general conclusion, particularly in the Ohio River basin, that the only way the problem can be resolved is at the source. This means that the phenols must be completely removed from the wastes, either by recovery or by destruction.

Recovery methods have been in vogue for many years, including the use of solid absorbents, such as activated carbon; liquid solvents, such as benzol; and volatilization, as in a dephenolizer. Of these, the Koppers' dephenolizing unit has probably been the most popular, particularly at coke and gas plants, where the phenol content frequently reaches several thousand parts per million. These units can be operated with such efficiency that the phenolic content of the final waste will amount to only a few parts per million; a good average is perhaps on the order of 25 or 35 p.p.m., but an average of this magnitude is generally too great for most water supply streams, particularly when several such phenol-producing plants are located on a single stream.

Destruction methods are used primarily for polishing purposes; namely, to remove the small amount of phenol left in the discharge from dephenolizing units or the phenol of various other waste discharges when the phenol content is less than 200 p.p.m. or the volume of higher concentration is relatively small. Destruction of phenols is accomplished by either biological or chemical oxidation.

That chemical oxidation is an effective method of phenol destruction is well known. Ingols and Ridenour (2) have published the reactions that take place with chlorine. That it is a practical method for removal of phenols from drinking water has been demonstrated in practice, as illustrated by the use of break-point chlorination at several water treatment plants. In each case it is probable that the phenol content of the water never exceeded 1.0 p.p.m.

That chlorine oxidation of high concentrations (10 to 200 p.p.m.) of phenol is practical had not been fully demonstrated, prior to the laboratory and pilot plant work at the Hamilton (Ohio) Coke Division of the Armco Steel Corporation, except by the Dow Company at Midland, Mich. The work done at Hamilton and reported in this paper covers the chlorination of a waste containing many types of phenols, called mixed phenols. Work on a waste containing one phenolic compound, phenol only, and likewise reported in this paper was studied at the Pequanoc Rubber Co., Butler, N. J.

Oxidation of Phenol as Mixed Phenols in Waste

The Ohio River Valley Water Sanitation Commission, recognizing the above factors, placed phenol destruction or removal at the source high on their study calendar. At the instigation of this commission, cooperative laboratory and pilot plant studies on the oxidation of mixed phenols with chlorine were carried out. Those taking part in the study, in addition to the commission, which acted as a coordinator, were the U.S.P.H.S., the Ohio State Health Department, the Armco Steel Corporation, and Wallace & Tiernan. The laboratory work was completed late in 1949 and the pilot plant work was done during the latter part of 1950.

The analysis of the data accumulated indicates that (a) destruction of phenols in phenol-bearing wastes can be effected by chlorination; (b) the major demand for chlorine in the oxidation of phenols in phenol-bearing wastes is due to accompanying reducing constituents (the theoretical ratio

of chlorine to phenols for their destruction is on the order of 6:1, whereas the total chlorine demand of some of the wastes containing as little as 20 p.p.m. phenol was as high as 4,000 p.p.m.); and (c) acidification and coagulation had little effect either on phenol reduction or on chlorine demand reduction. No analytical data were obtained on the additional benefits of chlorination on this type of waste, such as color removal.

Laboratory Studies

For these studies a sample of the dephenolized and deammoniated coke oven condensate waste was collected daily. The following is a typical analysis of the waste used:

Cyanides and cyanates—low concentration only.
Sulfides—less than 100 p.p.m.
Chlorides—7,000 to 9,700 p.p.m.
Oxygen consumed—from 1,400 to 1,800 p.p.m. (about one-half the oxygen consumed as measured by the dichromate reflux method was due to chlorides).
B.O.D.—300 to 400 p.p.m.
Ammonia—from 10 to 2,390 p.p.m. (variation due to drop in pH in fixed leg of ammonia still).
pH—11.0 on fixed leg of ammonia still as ordinarily operated for maximum ammonia recovery.
Temperature—95° to 100° C. as discharged from the still.

At the start of the work at Hamilton there was considerable doubt as to what results might be obtained as a result of chlorination on the appearance and color of a waste where the mixed phenol content might run as high as 200 p.p.m. The effect of chlorine is shown in Figure 1. The sample on the left is the raw waste, dark in color and typical of coke plant dephenolized wastes. The other samples are the same waste treated with 5,000, 7,500, and 10,000 p.p.m. chlorine, respectively, from left to right. It is to be noted that the sample on the right is practically water white, and the odor in this sample was at a minimum.

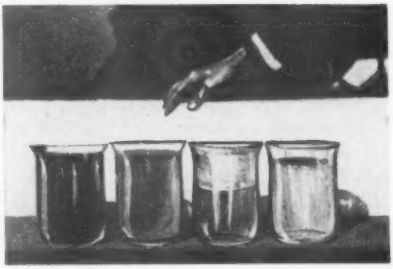

FIGURE 1.—Effect of chlorine on waste containing mixed phenols showing, left to right, raw waste, and same waste treated with 5,000, 7,500, and 10,000 p.p.m. chlorine, respectively.

In this particular instance only one analysis was made other than the observations noted above; namely, a residual chlorine test that indicated that most of the chlorine applied was consumed by the waste. This demonstrated that the chlorine probably oxidized the mixed phenols, and in so doing removed color as well. All subsequent work at Hamilton was devoted to a search for the most economical method for the treatment of the waste to destroy these mixed phenols without giving further attention to color reduction.

Considerable time was devoted to methods that would either reduce the phenol content of the waste or result in a reduction of the chlorine demand. Consideration was given to accomplishing these ends by acidification and coagulation which, if found successful, would be considered as pretreatment ahead of chlorination. Other oxidants considered for the destruction of phenols included potassium permanganate and chlorine dioxide.

Acidification

The literature indicated that possibly a large portion of the phenols could be precipitated by acidification.

This was tried by adding acid progressively on separate samples until the pH had been lowered to 4.0. It had little or no effect on the waste other than a slight reduction (not more than 6 per cent) in the phenol content.

Coagulation

Coagulation with iron salts and alum or combinations thereof at various pH levels has frequently lowered the chlorine demand of various wastes, thereby making chlorination more economical. As little data on coagulation could be found in the literature relating to phenol removal, several tests were devoted to this subject. The procedure in each case was to add the coagulant, adjust to various pH levels, stir, settle, and decant the supernatant. All analytical results reported are on the supernatant.

The results shown in Table I are those obtained with doses of coagulant up to 250 grains per gallon and sufficient lime or acid to adjust to the indicated pH. The best results in this range of 1 to 250 g.p.g. for each coagulant, together with chemical costs, are the only ones given. All costs were computed on the maximum coagulant requirements. In each case the cost of lime or acid was a very minor portion of the total cost per 1,000 gal. of waste treated.

The greatest removal of phenol that could be obtained by any of the chemical precipitation methods used was 20.6 per cent. This was accomplished with a combination of ferrous sulfate, alum, and acid at a total cost of $1.45 per 1,000 gal.

It is perhaps pertinent to say that in none of these tests was there a progressive removal with increasing application of any of the seven coagulants. Reductions in chlorine demand are not shown in Table I because they were insignificant.

Oxidation with Potassium Permanganate

Potassium permanganate is a strong oxidizing agent and it was theorized that perhaps this chemical might completely oxidize the phenols in the waste, particularly since the temperature of the waste as it leaves the dephenolizing unit is approximately 95° C. To check this theory, permanganate was added to samples at a temperature of 95° C. in increasing increments up to 1,000 p.p.m. at both high and low pH values. In contrast to the coagulation tests, phenol reductions increased with increasing applications of permanganate with a maximum removal of 78

TABLE I.—Removal of Phenols in Coke Plant Still Waste by Chemical Precipitation

Chemicals Used	Final pH	Phenol in Raw Waste (p.p.m.)	Max. Phenol Removal		Maximum Chemical Cost ($)[1,2]
			(p.p.m.)	(%)	
Alum (1 to 250 g.p.g.), with lime	8.7	125	13	10.4	0.65
Alum (1 to 250 g.p.g.), with acid	4.5	95	15	15.8	1.05
Ferric sulfate (1 to 250 g.p.g.), with lime	10.0	115	12	10.4	0.72
Ferric sulfate (1 to 250 g.p.g.), with acid	5.1	125	13	10.4	0.62
Ferrous sulfate (1 to 250 g.p.g.), with lime	9.4	107	12	11.2	0.75
Ferrous sulfate (1 to 250 g.p.g.), with acid	2.7	125	21	16.8	1.20
Ferrous sulfate (1 to 250 g.p.g.), and alum (1 to 250 g.p.g.), with acid or lime	9.5	107	22	20.6	1.45

[1] Per 1,000 gal. of waste.

[2] Costs based on aluminum sulfate, commercial ground, at $35 per ton; ferric sulfate at $35 per ton; ferrous sulfate at $35 per ton; sulfuric acid, 66° Bé., at $2.50 per 100 lb.; and lime, hydrated, at $15 per ton.

p.p.m. out of a total phenol content of 125 p.p.m., representing a removal of 62.4 per cent. For only partial removal and in consideration of other chemical treatment, such as chlorination for complete removal, the cost was high. For this partial removal of phenol at high pH, the cost amounted to $1.83 per 1,000 gal. and at low pH it amounted to $2.50 per 1,000 gal. based on a permanganate cost of $0.22 per lb. and sulfuric acid at $0.02 per lb.

Oxidation and Destruction with Chlorine

The reaction between chlorine and phenols can proceed in one of two directions, depending upon the pH of the solution after chlorination. If the final pH is less than 7.0, a chlorinating effect will predominate, leading to the production of chlorophenolic derivatives, many of which possess a more intense and more persistent odor than the original phenols. If the final pH of the solution after chlorination is above 7.0, oxidation will take place, resulting in the destruction of the phenols. Also, sufficient chlorine must be applied to produce a substantial chlorine residual, otherwise chlorophenolic derivatives are formed even under alkaline conditions.

Preliminary to the start of the main chlorination tests, the validity of the above statements was checked. In all cases it was found that whenever chlorination was carried out on the acid side of neutrality or when insufficient chlorine was applied at any pH, strong odors of chlorophenols were produced.

In this part of the work, chlorine was applied as a hypochlorite. pH adjustments were made immediately after adding the chlorine. Inasmuch as sodium hypochlorite contains considerable excess alkali, the pH always had a tendency to increase because of the heavy doses of chlorine used. In almost every case it was thus necessary to adjust the pH downward to the desired level with acid.

This phase of the work proved to be very interesting, in fact at times dramatic. The pH of the waste being chlorinated was approximately 10.5 to 12.0. When the chlorine in the form of hypochlorite was first added, nothing happened; but as the pH was adjusted downward with acid, bubbles of gas began to appear at approximately pH 9.0. At pH 8.5 bubbling was so profuse that a heavy froth accumulated on the surface and at the same time the color changed from a reddish black to a light orange, or colorless, depending upon the amount of chlorine applied. Within 5 min. all visible action ceased.

The samples were allowed to stand for various periods, usually 10 min., 1 hr., and 20 hr. At the end of each retention period the total chlorine residual was determined amperometrically and a portion of the sample was dechlorinated for phenol determination. The Gibbs test and the DAAP (distilled aminoantipyrene) test as modified by Dannis (4) were used throughout the work.

The progressive destruction of phenols, by the DAAP method, with increasing dosages of chlorine and at various times of contact is shown in Figure 2. It is to be noted that maximum destruction of phenols is accomplished at a dosage of approximately 5,000 p.p.m. Further applications of chlorine did not accomplish significant reductions. It is also to be noted that little additional phenol was removed with time. This apparently checks with the observation mentioned above regarding physical activity. This also checked in the pilot plant study, indicating that phenol destruction with chlorine is exceedingly rapid, showing that long contact with chlorine is not necessary for phenol destruction.

It was also significant, although not shown in Figure 2, that the odors of chlorophenol were very strong when the phenols were only partially re-

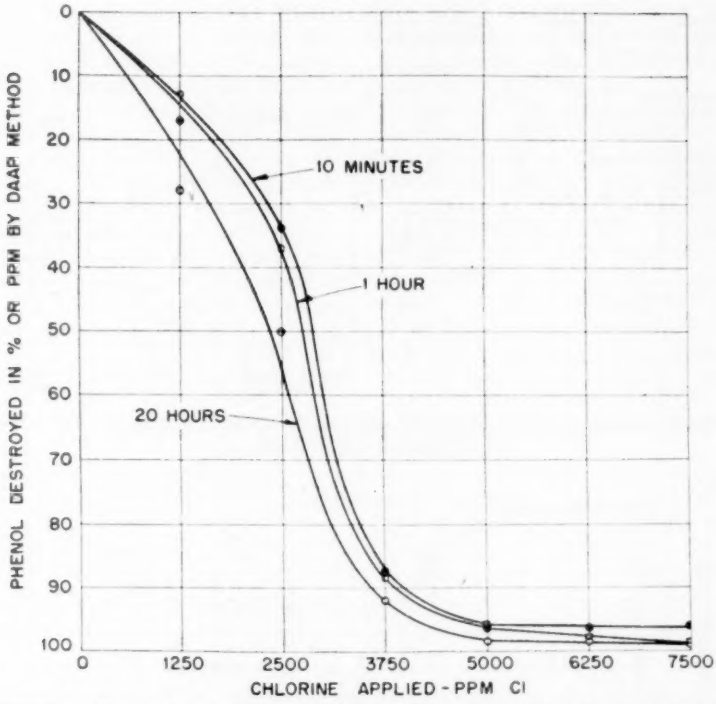

FIGURE 2.—Destruction of phenols (approximately 100 p.p.m.) in coke plant still waste by chlorine (at pH above 7.0) for various retention times (laboratory data).

moved; that is, at chlorine dosages less than 5,000 p.p.m. (less than a chlorine residual at pH values above 7.0). There were no chlorophenol odors at these pH's when chlorination reached or exceeded 5,000 p.p.m. (sufficient to give a strong chlorine residual). This confirmed the fact that chlorophenols are formed even at the proper pH level when chlorination is stopped short of a chlorine residual and are absent when a residual is present. Chlorine residuals of 50 to 200 p.p.m. were produced at the 5,000-p.p.m. and higher dosages depicted in Figure 2.

If the 6:1 chlorine to phenol ratio of Ingols and Ridenour (2) is accepted as theoretical (and if 10:1 is accepted as a practical ratio), the chlorine demand of the phenol (100 p.p.m.) for the 5,000 p.p.m. application is on the order of 1,000 p.p.m., leaving a demand for other compounds of approximately 4,000 p.p.m.

The pilot plant used (Figure 3) in these experiments was constructed by Armco Steel Corp. to handle a continuous flow of 2 g.p.m. A 1,000-gal. capacity holding tank was provided to insure a uniform waste for a day's run. This was equipped with steam coils for temperature control.

To avoid dilution difficulties, the chlorinator was operated by pumping the waste in the holding tank through the chlorinator injector. Thus, the waste took the place of water in the chlorinator operation. This is normal practice where water is at a premium or where dilution cannot be tolerated.

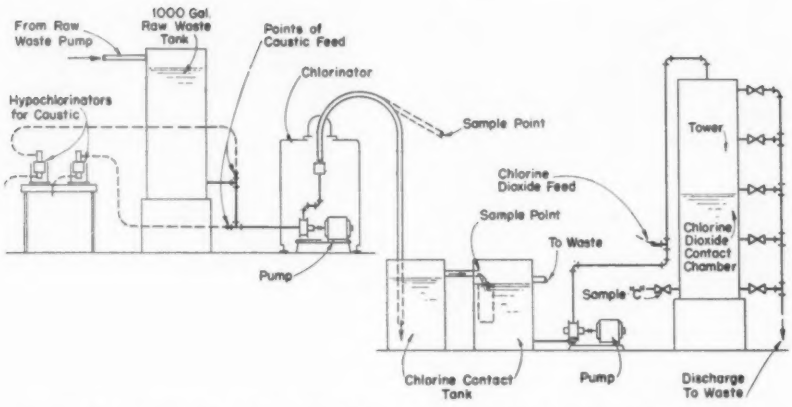

FIGURE 3.—Pilot plant for chlorination and chlorine dioxide treatment of phenol wastes at by-product coke plant.

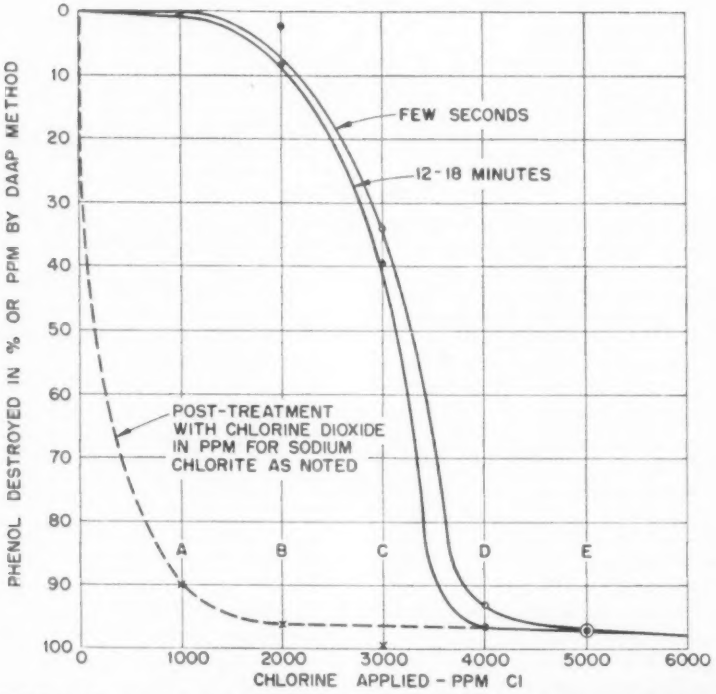

FIGURE 4.—Destruction of phenols (approximately 100 p.p.m.) in coke plant still waste by chlorine (at pH above 7.0) for various retention times (pilot plant data).

Following chlorination the waste passed into contact chambers and thence either to waste if no further treatment was used, or to the chlorine dioxide tower when post-treatment with the latter gas was used. Pilot plant samples for analysis were collected from the discharge of the chlorinator, a point where the contact was exceedingly short (2 to 3 sec.), and at the effluent from the contact chambers, where the contact could be varied. The usual contact used was in the range of 12 to 18 min.

The DAAP method for phenol analysis was used, as in the laboratory work. The results of the treatment are shown in Figure 4, on which are superimposed data for chlorine dioxide treatment following the application of chlorine. These results bring out more clearly than did the laboratory study (Figure 2) the rapidity of the reaction between chlorine and phenols. It not only confirmed the suspicion that the reaction is exceedingly rapid, but shows that the reaction is, for all practical purposes, instantaneous.

It also is significant to note that the use of 2,000 p.p.m. chlorine followed by the application of 1,800 p.p.m. sodium chlorite results in approximately the same phenol removal as is accomplished by the application of 4,000 p.p.m. chlorine alone; namely, a removal of 96.6 per cent.

The costs of the various treatments shown in Figure 4 are presented in Table II, to give a comparative picture of the meaning of the various applications. On a p.p.m. basis such a comparison might seem to be at some variance.

In Figure 4 the question might properly be asked: "Would not the use of 1,800 p.p.m. chlorine dioxide (14.8 lb.), either alone or in combination with 2,000 p.p.m. (16.7 lb.) chlorine, be the proper treatment at B?" From a straight analytical viewpoint the answer could very properly be yes. But from a cost standpoint the answer is very strongly in favor of a chlorine dosage of 4,000 p.p.m. alone (33.3 lb.) at D. This is because chlorite alone, even without the chlorine necessary to convert it into chlorine dioxide, would cost $7.40 per 1,000 gallons of waste, as opposed to a cost of only $2.91 per 1,000 gal. for the 4,000-p.p.m. chlorine dosage.

In computing costs it is recognized there may be many variants depending upon the price of chemicals. It is

TABLE II.—Cost of Chemical Treatment of Coke Plant Still Waste as Indicated by Pilot Plant Study[1]

Chem. Appl. in Pilot Plant at Points in Fig. 4	Chemicals Per 1,000 Gal. Waste								Total Cost ($)
	Sodium Chlorite		Chlorine for Chlorite		Chlorine for Chlorination		Hyd. Lime for Chlorination		
	Amount (lb.)	Cost ($)	Amount (lb.)	Cost ($)	Amount (lb.)	Cost ($)	Amount (lb.)	Cost ($)	
A	11.5	5.75	3.8	0.30	8.3	0.67	0.0	0.00	6.72
B	14.8	7.40	4.9	0.39	16.7	1.34	10.5	0.08	9.21
C	9.4	4.70	3.1	0.25	25.0	2.00	21.0	0.16	7.11
D	0.0	0.0	0.0	0.00	33.3	2.67	31.5	0.24	2.91
E	0.0	0.0	0.0	0.00	41.7	3.34	42.0	0.32	3.66

[1] Costs based on sodium chlorite at $0.50 per lb.; chlorine at $0.08 per lb.; and lime, hydrated, at $15.00 per ton.

believed that the unit costs used in Table II, if anything, are on the high side, particularly in the case of chlorine and lime. When chlorine is used in bulk it appears that the $2.91 cost per 1,000 gal. for chlorine and lime can be greatly reduced, possibly to $1.25 to $1.50 per 1,000 gal.

Oxidation of Phenol as Phenol Only

Conditions on the Pequannock River at the Pequanoc Rubber Co., Butler, N. J., are the exact opposite to those in the Ohio River Basin. The stream is small and taste- and odor-producing wastes entering the stream are reflected in the quality of the finished water of the Little Falls filtration plant of the Passaic Valley Water Supply Commission within 6 to 12 hr.

Phenol is present in one of the constituents used in the reclaiming of rubber at Butler and practically all the phenol used appears in the waste unchanged as pure phenol. Although the concentration in the waste is low, seldom amounting to more than 10 p.p.m., the volume is relatively high (50,000 to 100,000 g.p.d.), which shows that a considerable amount of phenol is discharged to the stream daily. Furthermore, the flow time from the plant at Butler to the water purification plant at Little Falls is so short that reduction by natural oxidation is far from complete at the time the water is processed for domestic purposes. Thus, it was imperative that the phenol in this industrial waste be removed at the source.

Preliminary laboratory work at Butler showed chlorine to be a more economical chemical for the destruction of phenol in wastes than chlorine dioxide. This preliminary work also showed chlorine to be very effective in the removal of the exceedingly high color and the extremely offensive odors in the raw waste, neither of which was due to the phenol content.

On the basis of these preliminary findings, the pilot plant (Figure 5) was constructed to include the functions of coagulation, settling, and chlorination. Inasmuch as the waste from the reclaiming process consisted of two types—one acid, the other alkaline—and because they could not be

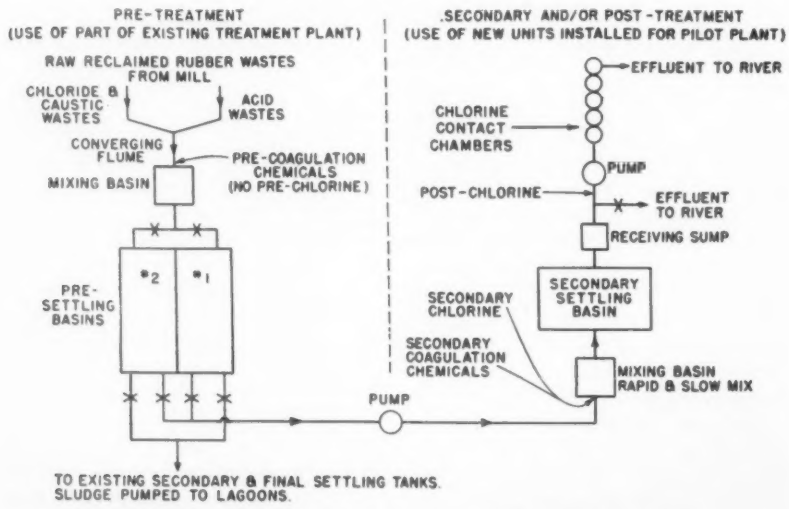

FIGURE 5.—Flow diagram of reclaimed rubber waste pilot plant.

TABLE III.—Effect of Coagulation and Chlorination in Pilot Plant Operation, Pequanoc Rubber Co., Butler, N. J.

Treatment[1]				Analysis of Effluents							
				Turbidity		Color		Odor		Phenol	
No.	Pre. 24 Hr.	Sec. 4 Hr.	Post 40 Min.	(p.p.m.)	Removal (%)	(p.p.m.)	Removal (%)	Thresh. No.	Removal (%)	(p.p.m.)	Removal (%)
1	COS	S	CLC	272	88.5	77	93	7470	−40	.23	95
2	COS	COS	CLC	155	97.8	2120	80	6560	−13	.00	100
Av.					93.2		86.5		−26.5		97.5
3	S	CLS	—	96	99	200	87	600	85	.00	100
4	COS	CLS	—	44	99.4	66	99	1409	82	.00	100
Av.					99.2		93		83.5		100

[1] S = settling only; COS = coagulation and settling; CLS = chlorination and settling; and CLC = chlorination and chlorine contact.

separated without a major engineering operation, it was necessary to blend the two for use in the pilot work. This was done by bringing the pH of the acid waste to the pH of the alkaline waste with lime, and by discharging both to the presettling basins, from which they were pumped to the pilot plant.

All of the phenol was contained in the alkaline waste. Because the lime-treated acid waste was mixed with the alkaline waste, the phenol content of the alkaline waste was diluted to some extent. Cognizance was taken of this dilution factor in designing the full-scale plant. Also, in the data hereinafter presented it is recognized that the demands for chlorine on full-plant operation and on the alkaline waste alone might be considerably greater than shown in this work, because the chlorine demand of the acid waste was low.

Choice of a coagulant for chemical precipitation or chemical reactant for pretreatment was difficult, as reported by Seehrist and Chamberlin (3). Ferric chloride, used at a high pH, behaved badly as a coagulant or reactant, and therefore gave poorer results than settling alone. Alum performed less favorably than settling from the clarification standpoint, but better for color and odor removal on a percentage-wise basis. Copperas, over a wide pH range, performed the best as a coagulant or reactant, not only from the standpoint of color removal, but also from the standpoint of clarification and odor removal. None of the coagulants decreased the chlorine demand of the wastes over that obtained by settling alone.

In analyzing these data on the pilot plant study (Table III), it was concluded that treatments 1 and 2 would not suffice because the over-all efficiency was vastly inferior to treatments 3 and 4. Had the goal been phenol removal alone, either of the first two would probably have been acceptable, but at this plant both color and odor had to be taken into consideration.

It should be pointed out that chlorination, in one instance (treatment 1) did not completely eliminate the phenols. An examination of this particular treatment showed that the pH of the chlorinated wastes had dropped far below 7.0 for a period of 30 min. or so. This indicates the necessity, when chlorinating for phenol removal, of having automatic pH control.

Further comparison of the various chlorinated wastes shows that in every instance in which the chlorine retention

TABLE IV.—Coagulation and Chlorination Costs, Pilot Plant Studies, Pequanoc Rubber Co., Butler, N. J.

Treatment No.[1]	Chemicals Per 1,000 Gal. Waste[2]						
	Copperas		Chlorine Applied		Lime		Total Cost ($)
	(lb.)	Cost ($)	(lb.)	Cost ($)	(lb.)	Cost ($)	
1	14.3	0.25	8.1	0.65	9.7	0.07	0.97
2	28.6	0.50	12.3	0.98	14.8	0.11	1.59
3	0.0	0.00	9.3	0.74	11.2	0.08	0.82
4	14.3	0.25	10.8	0.86	13.0	0.10	1.21

[1] Type of treatment as for Table III, with 100 g.p.g. of copperas and chlorine.

[2] Costs based on ferrous sulfate (copperas) at $35 per ton; chlorine at $0.08 per pound; and lime, hydrated, at $15 per ton.

was long (in secondary treatment) the color and odor removals were considerably better than those in which the chlorine retention time was short (in posttreatment). Short retention times were detrimental to odor removal; in a few instances the odor was increased. This increase can be contributed to chlorinated odors and the fact that the retention time was insufficient (40 min.) to destroy the odors of organic origin. It can be concluded that a chlorine retention time of not less than 3.5 hr. is necessary for proper odor control.

The costs of all treatments appearing in Table III are shown in Table IV. These costs were computed using copperas as a coagulant because it showed best results throughout the work, particularly as to color reduction. Using copperas, chlorine, and lime in treatments 3 and 4, it is to be noted that the chemical cost per 1,000 gal. was approximately $1.00. In a full-scale plant in which the acid and alkali wastes are separated (in the pilot plant they were combined) and only the alkali wastes are chlorinated, chlorine demand requirements would be increased, but not greater than twice the cost figures shown in Table IV.

On the basis of these data a complete plant was designed, utilizing insofar as possible existing basins and structures. In the designed plant the wastes are separated. The alkaline, phenol-containing portion is treated with coagulants and chlorine. The treated effluent is merged in a large holding basin with the acid waste. This lowers the pH of the alkaline portion, tends to raise the pH of the acid portion, and neutralizes any excess chlorine left after treatment.

Unfortunately, the operating figures are not available, but indications are that all phenols are being removed, the color is being changed from a dark amber to a pale yellow, and the odor has disappeared.

From these two experiences it has been concluded that (a) phenols can be oxidized rapidly with chlorine; (b) chlorine for the oxidation of phenols has the additional benefits of color and odor removal; (c) the cost is not prohibitive, provided the volume *versus* concentration *versus* chlorine demand factors are reasonable; and (d) the two factors, chlorine demand and additional chlorination benefits, be studied on laboratory and pilot plant scale prior to full plant design for any phenol-bearing waste.

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DISCUSSION

By Grant A. Pettit

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As brought out in Mr. Griffin's paper, the problem of the elimination of phenolic compounds is not a new one. Attention has been given to this problem by a number of industries, with varying degrees of success toward eliminating phenolic wastes either through process changes or destruction. In the case of the by-product coke industry, through operation of recovery methods such as liquid or vapor extraction, and by changes in operation, approximately 85 per cent of the phenol load to the streams has been eliminated. The remaining small percentage may not have proved too great a load for the streams to handle in past years, but with the great industrial expansion and the introduction of new industries and processes it has become a problem that is not easily or completely solved.

The cooperative study, as instigated by the Ohio River Valley Water Sanitation Commission, was set up to study the chemical oxidation aspects of treating the dephenolized still wastes from the Armco Steel Corporation's coke plant at Hamilton, Ohio. This waste amounts to about 30 gal. per ton of coal carbonized and, as indicated in the paper, is of a very complicated nature. The composition of this waste may vary considerably, due to the coal used, the coking time, and the temperature of carbonization.

Mr. Griffin has covered very thoroughly the laboratory and pilot plant work in connection with the oxidation of the phenols in this waste with chlorine. In addition to chlorine, two other oxidizing agents were tried. Laboratory and pilot plant work was carried on under the same conditions, using both ozone and chlorine dioxide. Ozone oxidation was studied by the Ozone Processes Division of the Welsbach Corporation. Experiments with chlorine dioxide were undertaken by the Mathieson Chemical Corporation.

From the laboratory experiments it was found that all three oxidizing agents could be used for the destruction of the phenols in this waste. The later pilot plant experiments, in each instance, verified for all practical purposes the results of the laboratory work. The following summary of the results obtained from the pliot plant experiments covering all three oxidants will be of interest:

1. Phenols can be oxidized by chlorine, ozone, and chlorine dioxide. Comparable results were obtained with 5,000 p.p.m. chlorine, 700 p.p.m. ozone, and 1,800 p.p.m. sodium chlorite.

2. Reaction curves show a substantial reduction in phenol attained with small oxidant dosage, but increasingly high dosages are required as phenol is further reduced.

3. Oxygen consumed and biochemical oxygen demand were materially reduced (more than 60 per cent) by each of these oxidants.

4. Phenolic content of coke plant waste cannot be used as the sole basis for determination of the required dosage of oxidizing agent. Phenols represent but part of the oxidant demand. No correlation was found between oxygen consumed and oxidant demand.

5. No temperature adjustment of the waste is required for ozone or chlorine-dioxide treatment. Temperatures above 45° C. in chlorination may cause formation of chlorates, thus requiring larger chlorine dosages.

6. Chlorine treatment requires pH adjustment during oxidation, perferably to a range of 7.0 to 10.0. Ozone and chlorine dioxide oxidized the phe-

nol at all pH's tried. Best results were obtained for this waste by adding ozone or chlorine dioxide to the waste as it came from the still at pH above 11.5 and with no further adjustment in pH.

7. Chlorine treatment requires prior satisfaction of ammonia demand in order to reach the breakpoint potential necessary for phenol oxidation. Ammonia content of the waste has little or no effect on ozone or chlorine dioxide treatment.

8. Partial treatment is possible with both ozone and chlorine dioxide without formation of chlorophenols. Chlorination requires complete oxidation to prevent formation of chlorophenols.

9. Residual chlorine in a concentration of several hundred parts per million is required to reduce phenol to low concentrations or to effect complete removal. Excess chlorine can be removed by granular activated carbon. Residual ozone or chlorine dioxide can be controlled to less than 1 p.p.m. and requires no further treatment.

10. Chlorine content of waste is increased by an amount equivalent to chlorine dosage. Chlorine dioxide causes a small increase (about 1.5 per cent) in chlorides. Ozone causes no change.

11. Chlorine and chlorine dioxide in series did not seem advantageous, but a mixture of chlorine and chlorine dioxide simultaneously gave substantial reduction in chlorine dioxide dosage.

12. Additional information is required on methods of analysis for phenols to evaluate effects of these oxidants on concentrations less than 0.1 p.p.m. of phenol. But the adaptation of the aminoantipyrine method of analysis for phenols (DAAP), developed in connection with this research, was established as an excellent control for treatment by any of these oxidants.

13. Foaming was experienced with both chlorine and ozone. Chlorine dioxide did not indicate a foaming problem. An increase in the temperature of the waste reduced foaming.

14. Most effective utilization of the oxidants can be secured only after certain plant design problems have been overcome.

15. Economics and merits of application of each process will depend upon the volume and strength of wastes to be handled, the degree of treatment required, and other conditions that are peculiar to each problem. Relative cost of treatment may be estimated from the dosage data, but it must be realized that the chemical cost is only part of the total cost of such treatment. The equipment cost may be in the opposite order from the chemical cost. Preliminary and post-treatment, if necessary, control features, and operating expense must be considered for each process. Therefore, any determination on the basis of chemical cost only may prove disastrous because of the other variables involved.

The foregoing summary of the findings of the pilot plant study brings out again the various points as set out in the conclusions drawn in the paper. The last point in these conclusions should again be emphasized, that is, that each installation should be preceded by some laboratory work, followed by pilot plant work if necessary. This is particularly true in the case of coke plant wastes.

In conclusion, it is felt that this cooperative study has been very successful. Three new methods of treatment of this type of wastes have been added to the list of treatment possibilities. It has been demonstrated that a cooperative venture of this type can be carried to a successful conclusion and, last but not least, that a better understanding by the regulatory as well as industrial personnel of the industrial waste problem involved is established.

The complete report of all the work carried on at the Hamilton coke plant

has been published by the Ohio River Valley Water Sanitation Commission, under the heading "Phenol Wastes—Treatment by Chemical Oxidation." This report is a factual report edited by all of the participants and is very complete, giving all the pilot plant experimental data. Copies of the report are available by writing to the Commission's office, in Cincinnati, Ohio.

BUREAU OF MINES EMPHASIZES POLLUTION CONTROL

B. P. Martinez, a chemical engineering graduate of the Massachusetts Institute of Technology, has been named chief of the U. S. Bureau of Mines' Stream Pollution Research Section for the Northeastern Region at College Park, Md., H. P. Greenwald, Regional Director, has announced.

Greenwald said all activities of the section in the 17 Northeastern States will be consolidated at College Park, thus leading to more effective use of laboratory equipment and other facilities for instituting Department of the Interior programs for preventing or lessening stream pollution by industrial wastes of mineral origin.

Tracing the Bureau's activities in this field over a period of many years, Greenwald said it shared in the development of the only practical method—mine sealing—now used to decrease the volume and acidity of waters from depleted mining areas or abandoned workings.

He added that the Federal Agency also was instrumental in providing information on methods of controlling and preventing silt and culm depositions in surface water channels, has aided in abating pollution from oil well brines, and also has cooperated in eliminating pollution caused by rolling oils discharged from steel finishing mills.

"The Bureau of Mines is well equipped to assist in developing additional practical methods for abating and preventing pollution originating from chemical, mining, metallurgical, petroleum, and related industries," Greenwald commented. "Our technologists plan additional laboratory and field studies to help protect our streams and rivers from harmful materials of mineral origin. We likewise maintain extensive reference files which contain valuable research information and which are available to industries, state, and local agencies, and others concerned with the stream pollution problem."

Martinez was process engineer for a steel firm at Sparrows Point, Md., before accepting the new assignment with the Bureau of Mines. He spent several years on research for controlling waste materials from steel mills and has helped design many large chemical plants.

RAG, ROPE, AND JUTE WASTES FROM SPECIALTY PAPER MILLS *

III. Chemical Treatment of Rope Cook Liquor

By Willem Rudolfs and N. L. Nemerow

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A rather extensive study of the chemical and biological treatments of rope waste was made, but this paper deals with the chemical treatment only. Rope waste was chosen because it represents approximately the medium between the relatively week jute waste and the strong rag waste, and its organic constituents were found to be similar in character to those in jute and rag wastes (1). Hence, it was assumed that optimum conditions ascertained for rope waste could be more or less projected to jute and rag wastes, and the results verified for all three wastes in a minimum number of experiments. Because it was found (2) that the cook liquor and first hour of wash-water waste contained 90 per cent of the total cook and wash B.O.D., a diluted cook liquor was used to represent this waste.

Plant Method of Chemical Treatment

The plant treatment of the cook liquor consists of the addition of 1 per cent $CaCl_2$ (by weight) and 0.25 per cent of alum (by weight) to the total cook liquor waste. After mixing, the waste is allowed to settle for about 6 hr. This treatment process was repeated in the laboratory, with results indicating that present mill treatment of the rope cooking liquor waste reduces the B.O.D. 14 per cent. The same treatment when applied to the rope mill beater wash waste gave the same percentage B.O.D. reduction. It is obvious that the present plant method of treating rope cook liquor waste does not remove the dissolved organic matter, but some clarification and color reduction are obtained.

Use of Various Chemicals

Optimum Combination of Alum and H_2SO_4

Sulfuric acid and alum were added to rope cook liquor, either singly or in combination, at various pH values. Color, sludge volume, turbidity, and B.O.D. values were obtained.

The pH of rope cook liquor must be lowered to 2.5 to obtain consistent precipitation of a portion believed to be the lignified fraction. Sulfuric acid precipitation alone reduced the turbidity by about half and caused the color to change from a brown-black to a light tan. No visible flocculation of rope cook liquor is caused by alum treatment until the pH has been lowered to 2.5. The amount of alum necessary is so high that there is no advantage in using alum rather than H_2SO_4; hence, the pH should be lowered with H_2SO_4 to cause precipitation as the first step in this chemical treatment. Sulfuric acid treatment removed 7 to 15 per cent of the rope cook liquor B.O.D. and produced a 15 to 58 per cent sludge volume, depending on the conditions of mixing and the pH at which the precipitation is carried out.

The alum dosage (as well as the quantity of H_2SO_4) depends on the concentration of rope cook liquor being treated. When the pH of a rope cook liquor diluted 12 times was lowered to 2.5 with H_2SO_4, a B.O.D. reduction and a sludge volume of 15 per

* Paper of the Journal Series, New Jersey Agricultural Experiment Station.

cent resulted, as well as a considerable reduction in turbidity. The optimum dosage for alum was 4,000 p.p.m. and a pH of 5 was the optimum for coagulation. The alum treatment caused an additional 21 per cent removal of B.O.D. and a turbidity of less than 25 p.p.m., but 35 per cent additional sludge volume. This made a total B.O.D. removal of 36 per cent and a sludge volume of about 50 per cent, after pH adjustment to 2.5 with H_2SO_4, settling, and alum treatment (0.4 per cent) of the supernatant at a pH of 5.

Ferric Chloride

Rope cook liquor was diluted 12 times with water and the optimum dosage of ferric chloride to cause the best floc, without lowering the pH below the alkaline isoelectric point of ferric chloride, was determined. This pH was found to be 11. The results on clarification and stabilization at this pH with Fe^{+++} doses of 0 to 384 p.p.m. show that the optimum dosage of $FeCl_3$ was 96 p.p.m. A maximum B.O.D. reduction of 27 per cent was obtained with a sludge volume of only 2 per cent, but an apparent slight turbidity because of the increase in color contributed by the $FeCl_3$ solution. This coagulant did not produce a very good floc.

Lime

Experiments were conducted with samples adjusted to a pH of 9.8 after various dosages (0 to 6,600 p.p.m.) of lime were added. The pH value of 9.8 was chosen because of the many claims that lime works best at a pH of 9.5 to 10.2. Color, sludge volume, turbidity, and B.O.D. were determined on the supernatants after flocculation and sedimentation. The results show that the optimum dosage of lime required for flocculation of the 1:12 diluted rope cook liquor was 5,800 p.p.m. It caused a 56 per cent reduction in turbidity, 6.6 per cent sludge production, some color removal, and about 12 per cent B.O.D. reduction. Slightly more lime resulted in less B.O.D. removal, despite better clarification with dosages up to 6,600 p.p.m. This coagulant has an advantage over $FeCl_3$ because it reduces the turbidity more than half.

$KMnO_4$ As an Aid to Alum

Potassium permanganate, a strong oxidizing agent, was used to oxidize the colloidal particles in the rope waste to such an extent that the electrolytic potential between these particles and the alum floc was increased to a maximum. Raw cook liquor was diluted 12 times and H_2SO_4 added to a pH of 2.5. Precipitation occurred and continued flocculation was induced by slow mixing. The waste was then settled and the supernatant treated with 4,000 p.p.m. alum at a pH of 5.5 with and without the addition of quantities of $KMnO_4$ varying from 25 to 100 p.p.m. The alum-treated supernatants were again flocculated and settled. The sludge volumes and B.O.D. values of the resulting supernatants were determined. The results show that alum under the described conditions caused a 39 per cent B.O.D. reduction, and an optimum $KMnO_4$ dosage (50 p.p.m.) used with the alum increased the B.O.D. reduction to 43 per cent. Previous experiments showed a B.O.D. reduction increase of 7 per cent when $KMnO_4$ was used in conjunction with alum. It is doubtful whether it would be practical to employ $KMnO_4$ in addition to alum to effect a 4 to 7 per cent increase in B.O.D. reduction. However, it is of interest and value to know that a relatively small quantity of $KMnO_4$ used together with alum as a coagulant will produce optimum B.O.D. reduction.

$MgCl_2$ and $MgSO_4$

The approximate coagulant dosage was predetermined and samples of 1:12 diluted rope cook liquor were treated with 1,500 to 6,000 p.p.m. $MgCl_2$, 5,000 to 9,000 p.p.m. $MgSo_4$, and 3,000 to 5,000 p.p.m. of a 1:1 mixture of $MgCl_2$ and $MgSO_4$. Sludge vol-

ume, turbidity, color, and B.O.D. reductions were determined in all cases. The results show that $MgCl_2$ in an optimum dosage of 5,000 p.p.m. at a pH of 10 caused a B.O.D. reduction of 21 per cent, a 2-hr. sludge volume of 19 per cent, and a turbidity reduction of more than 70 per cent. The resulting color was a clear straw. $MgSO_4$ was less effective than $MgCl_2$ when its optimum dosage of 7,000 p.p.m. was used. At a pH of 10.2 this dosage resulted in a B.O.D. reduction of 17 per cent, a 2-hour sludge volume of 17 per cent, and a turbidity reduction of 75 per cent. The resulting color was a dark straw. The 1:1 mixture of $MgCl_2$ and $MgSO_4$ when used at its optimum dosage of 4,000 p.p.m. was ineffective in clarification, causing an increase in turbidity of the treated rope waste, and resulted in a 25 per cent B.O.D. reduction.

These coagulants, whether used separately or as a mixture, caused not more than 25 per cent reduction in B.O.D. at pH values of about 10, although good flocculation and clarification occurred.

$MgCl_2$ and Alum

Magnesium chloride (5,000 p.p.m.) was added to rope cook liquor diluted 12 times, with a resulting pH of 10.2. The waste was then flocculated and settled. The supernatant from this stage of the treatment was dosed with 4,000 p.p.m. alum and caustic soda was added until the pH was 6. This waste was also flocculated and settled for 20 hr. before the supernatant was removed and examined for turbidity, apparent color, B.O.D. reduction, and sludge volumes. The results show that when the optimum dosage of $MgCl_2$ was added in the first stage of the treatment, a 10 per cent B.O.D. reduction, as well as a 2-hr. sludge volume of 27 per cent, resulted; that the color was reduced from brown to yellow; and that better than 70 per cent turbidity reduction was obtained. The alum added to this supernatant in the second stage of the treatment reduced the B.O.D. an additional 25 per cent and the effluent was rendered colorless. A total B.O.D. reduction of only 35 per per cent resulted from this 2-stage treatment, even though the waste was changed from brown to colorless. The results are an additional indication that the organic matter responsible for the high B.O.D. of rope waste is in solution and is not materially affected by chemical treatment.

Maximum Chemical Clarification of Rope Waste

The most practical, satisfactory individual chemical treatments of the diluted rope cook liquor found were combined into a single 3-stage chemical treatment process in an effort to obtain the maximum possible clarification.

Ferric chloride, 96 p.p.m. Fe^{+++}, was added with no pH adjustment (the coagulant addition caused the pH to drop to 11 where it was found to be most effective), then 50 per cent H_2SO_4 was added to the iron chloride supernatant to reduce the pH to 2.5. Finally 4,000 p.p.m. of alum were added to the supernatant from the acid-treated cook liquor and the pH was raised to 5.5 with NaOH. The results show that the first-stage treatment (ferric chloride) caused 16 per cent B.O.D. reduction and only 1 per cent sludge volume. The apparent turbidity of the waste was increased slightly by the ferric chloride addition. The second stage of the treatment (H_2SO_4) caused 8 per cent B.O.D. reduction; the total turbidity reduction of the waste after H_2SO_4 treatment was 62 per cent and the sludge volume 6.5 per cent. The third stage of the treatment (alum addition) caused an additional 36 per cent B.O.D. reduction and a 25 per cent sludge volume in the H_2SO_4 waste supernatant. The complete treatment resulted in a total B.O.D. reduction of 50 per cent and a total sludge volume of 27 per cent of the original diluted waste volume. The turbidity removal was more than

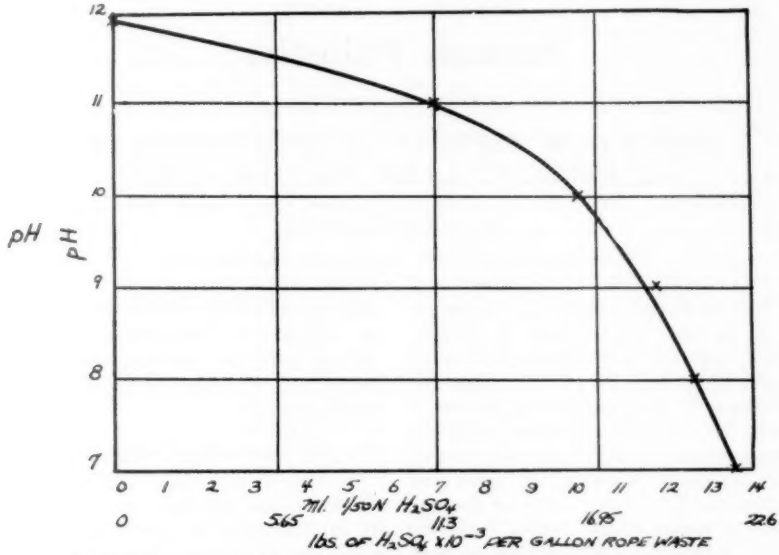

FIGURE 1.—Quantities of acid required for neutralization of rope waste.

82 per cent and the effluent practically colorless.

Neutralization of Rope Waste

The evidence obtained on chemical treatment indicated that secondary treatment is necessary to obtain more than 50 per cent B.O.D. reductions of cooking liquors. Since chemical acidification would be the first step in biological treatment, the various quantities of acid necessary to lower the pH of a mixture of rope cook liquor plus the first hour of beater wash water were determined. Rope wastes (1 part cook liquor plus 12 parts first-hour beater wash waste) were titrated to neutrality with 1/50 N H_2SO_4. The results (Figure 1) show that 50 per cent of the total acid required for complete neutralization of this waste lowered the pH to only 11, that 75 per cent lowered the pH to 10, and 87.5 per cent lowered the pH to 9. Since most biological treatment devices require the pH to be around 7, about 22 lb. of H_2SO_4 is required to neutralize 1,000 gal. of the waste.

Summary

A study of various methods of chemical treatment of rope wastes showed that, in general, most of the coagulants causing good clarification also produced excessive quantities of sludge and effected relatively little B.O.D. reduction. A 3-stage chemical treatment using $FeCl_3$, H_2SO_4, and alum in separate successive stages resulted in a total B.O.D. reduction of 50 per cent and a total sludge volume of 27 per cent of the original waste, with a turbidity reduction of greater than 82 per cent and practically colorless effluent. All other single or combinations of chemical coagulants investigated produced lower B.O.D. reductions.

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Stream Pollution

SOME NEW ASPECTS OF PHOSPHATES IN RELATION TO LAKE FERTILIZATION *

By Clair N. Sawyer

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The biological problems most prevalent in lakes are a result of prolific weed growths in littoral areas or of algal blooming. In the first case the nuisance is due largely to interference with recreational activities, such as boating and bathing; in the second case, it is a result of obnoxious tastes and odors carried in the water or generation of aerial odors of such intensity and repugnant character as to materially influence shoreline land usage.

Lakes vary greatly in their productivity of algal blooms and areas of rooted vegetation. Of late years, much evidence has accumulated to confirm the belief that inorganic and organic fertilizers containing nitrogen and phosphorus are the major factors influencing the extent of such growths. The fertilization studies of Swingle (12), Juday (7), and others on ponds and small lakes have been most convincing. Considerable circumstantial evidence has been presented to indict domestic sewage as an important source of fertilizing elements stimulating such growths. Hasler (6) has recently reviewed the literature and cites 37 lakes in Europe and the U. S. which, during the past century, have passed from well-behaved oligotrophic lakes to lakes of the eutrophic type. On many of the lakes cited, nuisance conditions have become so critical as to seriously impair riparian land values. The case of the Zurichsee in Switzerland undoubtedly presents the most convincing evidence of the damaging effect of domestic sewage.

Nitrogen and Phosphorus

According to Liebig's Law of the Minimum, the variation in productivity of land areas is most often determined by limitations imposed by a lack of some nutritional element. This premise has led to the general and highly successful practice of soil fertilization to balance the necessary nutrient elements in order to favor high productivity of the particular crop under cultivation.

It is reasonable to assume that micro and macro aquatic plants respond to the same factors. From the analysis of numerous algal forms (1), it has been shown that nitrogen and phosphorus are important elements involved in their synthesis. Cultural studies with the alga *Coccochloris peniocystis*, recently reported by Gerloff *et al.* (4), have shown that the growth of this particular organism can be greatly retarded by limiting the supply of nitrogen, phosphorus, sulfur, potassium, or magnesium, thus verifying application of the Law of the Minimum to algal forms. The same investigators have shown that a nitrogen-phosphorus ratio of 30 to 1 is optimum for growth of this particular algal form. This ratio is somewhat higher than the values of 15 to 18 indicated by the chemical analysis of sev-

* A contribution from the Sedgwick Memorial Laboratories, Mass. Inst. of Tech., Cambridge, Mass. Presented at 1951 Fall Meeting, New England Sewage Works Assn.; Providence, R. I.; Nov. 6–7, 1951.

eral algal forms as given by Birge and Juday (1).

From the results obtained during a two-year survey of 17 lakes in southern Wisconsin, Sawyer (10) concluded that nitrogen and phosphorus were the two fertilizing elements which regulated the biological productivity of those lakes. In some lakes domestic sewage was shown to be the major source of these critical fertilizing elements, and a high degree of correlation between nuisance conditions and extent of sewage fertilization was found. In analyzing his data with respect to biological behavior, he concluded that any lake showing concentrations in excess of 0.01 p.p.m. of inorganic phosphorus and 0.30 p.p.m. of inorganic nitrogen at the time of the spring overturn could be expected to produce algal blooms of such density as to cause nuisance. Thus, the critical level for both of these elements is very low, especially so for phosphorus.

Significance of Phosphorus

Ordinary domestic sewages contain from 15 to 35 p.p.m. of nitrogen and from 2 to 4 p.p.m. of phosphorus. A large percentage of these fertilizing elements exist in a readily available condition or become so during biological treatment or while undergoing stabilization by microorganisms in the receiving body of water. Consequently, it can be reasoned that sewage contains nitrogen and phosphorus in a ratio of about 8 to 1. This would indicate that domestic sewage is unduly rich in phosphorus and that further increase in the concentration occurring in sewage would have no serious effect.

Some indication of the fallacy of drawing such a conclusion can be drawn from the work of Einsele (2). In fertilization studies with inorganic phosphates, he found the phosphates quickly disappeared with little stimulation of phytoplankton growths. Some three months later, however, the phytoplankton began to propagate enormously with considerable increases in nitrogen. His explanation was that the added phosphates stimulated decomposition of bottom muds, thereby releasing sufficient nitrogen to cause the bloom of algae at the later date.

The writer has conducted laboratory experiments (5) which support Einsele's observations but allow quite another interpretation of the results. Test samples of natural waters from one source were enriched with equal volumes of normal sewage plant effluent, sewage plant effluent from which the nitrogen and phosphorus had been removed, and portions of the second effluent to which nitrogen and/or phosphorus had been added.

The samples of lake water to which had been added sewage effluent containing both nitrogen and phosphorus gave a marked growth response within a relatively short time. The effluent deficient in nitrogen and rich in phosphorus showed little response for a period of 120 days and then began to bloom profusely with blue-green algae. At the termination of the test, at about 170 days, the samples were analyzed for their nitrogen contents. The results are shown in Table I.

From the fact that a heavy growth of blue-green algae did occur in the presence of a plentiful supply of phosphorus and a deficiency of nitrogen and that nitrogen was simultaneously

TABLE I.—Nitrogen Fixation in Natural Waters Fertilized with Sewage Effluents of Various Characters

Mixture with Lake Water	Period (days)	Total Nitrogen (p.p.m.)		
		Start	Finish	Δ
Control sample	167	0.51	2.61	2.10
10% effluent	181	2.67	4.39	1.72
10% effluent minus its N and P	170	0.67	2.17	1.50
10% effluent minus its nitrogen	188	0.67	11.85	11.18

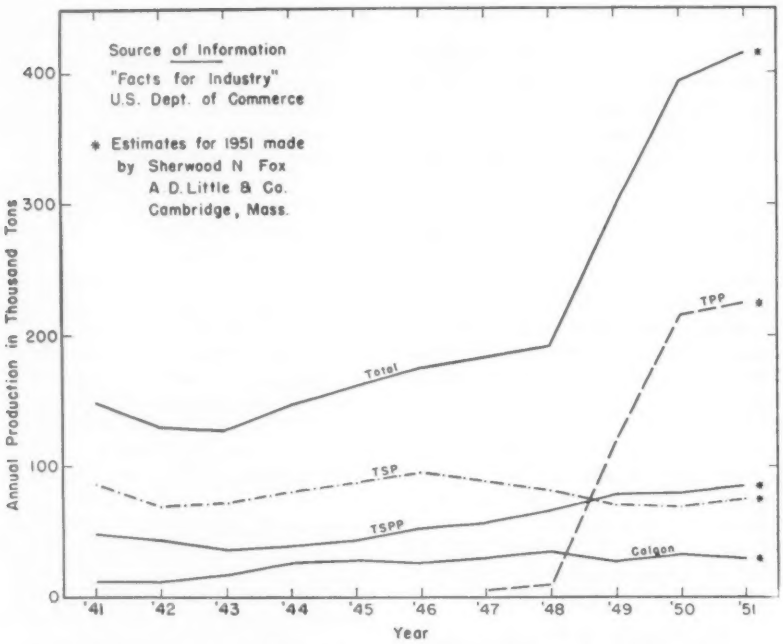

FIGURE 1.—U. S. production of major phosphates used in detergents.

fixed from the atmosphere, it may be concluded that phosphorus is a key element in the fertilization of natural bodies of water and that any deficiency of nitrogen can be obtained from the atmosphere. Therefore, control of the amount of phosphorus entering lakes becomes of considerable concern.

Within the past few years the National Institutes of Health have sponsored research at the University of Wisconsin on the removal of phosphorus from sewage and sewage plant effluents. Thus, the importance of phosphorus as a key element in the fertilization of algal forms is becoming generally recognized.

Syndets and Phosphorus

Almost everyone is aware of the rapid increase in the use and production of synthetic detergents, with a new record of 1,200,000,000 lb. for the year 1950. Marketing experts (14) predict a potential market of 2,500,000,000 lb. per year for the current U. S. population. Not so well known, however, is the fact that the complex phosphates are important constituents of almost all commercial detergents and that their use has grown by leaps and bounds also. Data on the production (13) of tri-sodium phosphate (TSP), and three complex phosphates, tetrasodium pyrophosphate (TSPP), sodium tripolyphosphate (TPP), and hexametaphosphate (Calgon), are shown in Figure 1. It can readily be seen that current consumption of phosphates in the detergent and water softening fields is about 2.5 times that prior to World War II and may be expected to rise to about 5 times that in view of the predicted possible market for synthetic detergents.

The question naturally arises as to the effect such quantities of additional phosphates will have on the phosphorus content of domestic sewages. Some years ago, Rudolfs (9) studied the phosphorus content of sewages from 12 separate sources and concluded that the per capita contribution of phosphorus ranges from 0.6 to 1.5 lb. per year. He cites reports of others who have indicated similar values. The writer (5) during a two-year survey (1942–44) at Madison, Wis., found the phosphorus contained in the sewage treatment plant effluent to equal 1.2 lb. per capita per year.

The total consumption of phosphates in the detergent and water softening industry during 1950 was 535,000 tons (3), or about 6.7 lb. per capita. On a weighted basis, the average phosphorus content was 23.4 per cent, equivalent to 1.57 lb. of phosphorus per capita per year. Thus, it seems likely that the phosphorus content of domestic sewage in the U.S. today is about twice what it was before the advent of modern syndets. Inasmuch as most of the phosphates so used do not form insoluble materials in the carriage water, they tend to pass through present day treatment plants and, therefore, are of real concern to those interested in controlling fertilization of aquatic areas.

The higher concentration of phosphates in sewages and effluents is going to make it necessary that consideration be given to removal of phosphorus from many effluents which previously would have been considered innocuous.

Removal of Phosphorus from Sewage

Biological Methods

It has been demonstrated by the writer (11) that phosphorus can be effectively removed from sewage by the activated sludge process, provided the B.O.D.-phosphorus ratio is properly adjusted. This method involves addition of carbonaceous matter to provide more material for microbial synthesis and, consequently, is not practical unless a source of such food is available locally, such as certain industrial wastes. The method, however, has the advantage of fixing excess nitrogen in the activated sludge produced, as well as phosphorus.

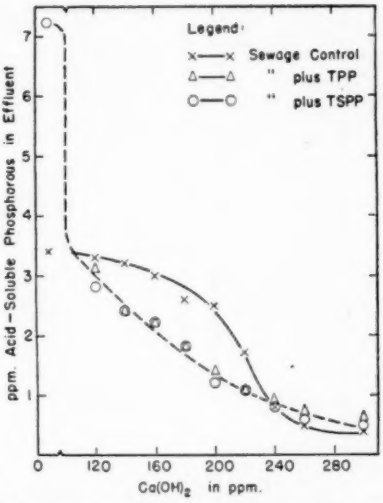

FIGURE 2.—Removal of phosphates from sewage by coagulation with lime.

Chemical Methods

Rudolfs (9) has reported on the removal of phosphates from sewage by coagulation with lime and has indicated it to be quite effective. Studies in the Sedgwick Memorial Laboratories have confirmed the results presented by Rudolfs. Similar studies with sewages enriched with the complex phosphates, TPP and TSPP, have shown them to be readily removed, also, without any appreciable increase in lime requirements. These data (Figure 2) indicate that the total soluble phosphorus content can be reduced to about 0.5 p.p.m. by lime treatment.

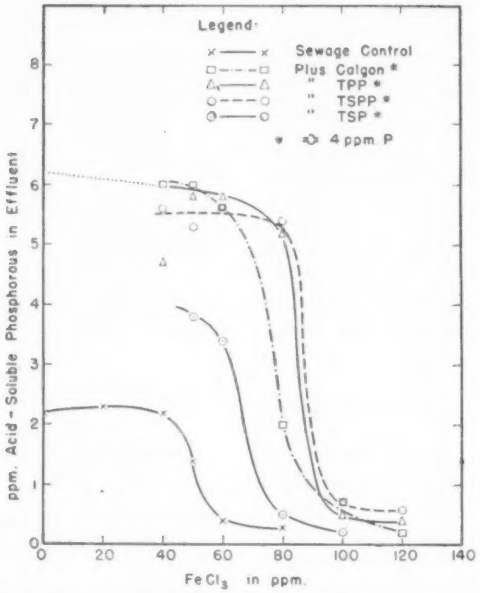

FIGURE 3.—Removal of phosphates from sewage by coagulation with ferric chloride.

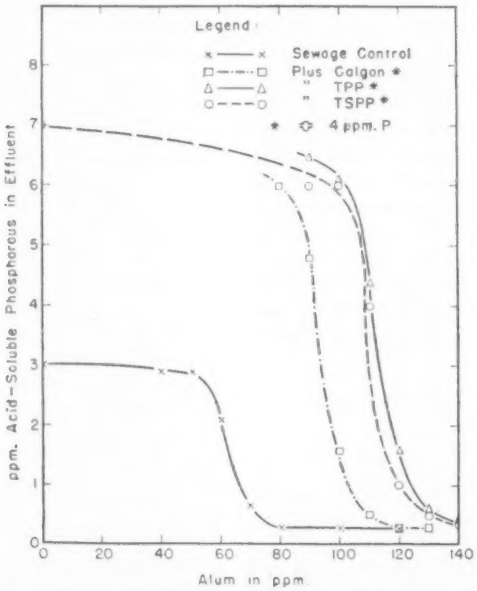

FIGURE 4.—Removal of phosphates from sewage by alum coagulation.

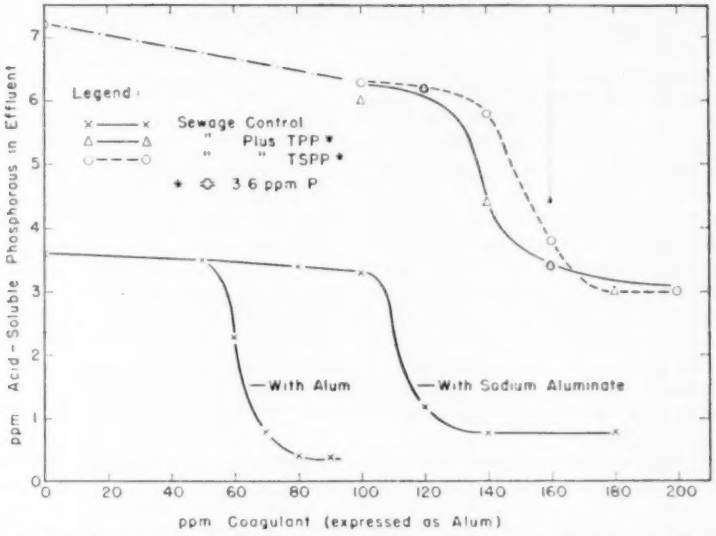

FIGURE 5.—Removal of phosphates from sewage by coagulation with sodium aluminate.

Ferric salts and aluminum sulfate (alum) have been proposed (11) for coagulation of phosphates from sewage. Results of studies with these coagulants are given in Figures 3 and 4. Both coagulants are highly effective in removing all forms of phosphates, but the coagulant requirements are markedly increased by the amount of phosphate present.

Alum has been proposed by Lea and Rohlich (8) as the most suitable co-

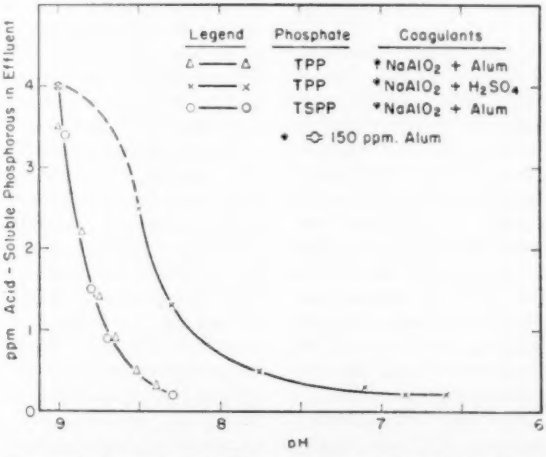

FIGURE 6.—Removal of complex phosphates by coagulation with sodium aluminate and pH adjustment with alum or sulfuric acid.

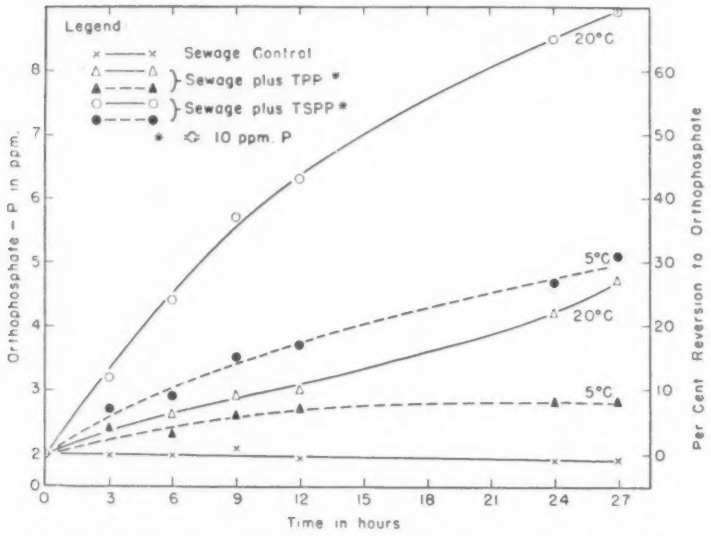

FIGURE 7.—Reversion of complex phosphates in sewage at 5° and 20° C.

agulant for the removal of phosphorus because the aluminum can be recovered from the sludge by treatment with caustic to form sodium aluminate and the phosphates can be separated as insoluble calcium salts suitable for use as fertilizer. In addition the sodium aluminate is re-usable for further coagulation.

Attempts to use sodium aluminate for removal of phosphorus from Boston sewage met with failure unless supplemental caustic was used to raise the pH, or alum or sulfuric acid was used to lower the pH into a favorable range. At high pH levels of 10 to 11 considerably more sodium aluminate was needed to remove the phosphorus than was required when alum alone was used. However, this is not an important consideration when a coagulating agent is being recovered and recycled. What is more critical is the fact that sodium aluminate was quite ineffective in removing the complex phosphates, such as TPP and TSPP, at the high pH levels. Data illustrating this point are given in Figure 5.

Results of studies using sodium aluminate as a coagulant at a lower pH range are given in Figure 6. These data show it to be a good coagulant for all forms of phosphates under these conditions. Good removals were obtained at pH levels below 8.6 when alum was used to control the pH. When sulfuric acid was used the pH had to be held to values below 8.0 to give comparable results.

Because in some situations it may be more desirable to use sodium aluminate as a coagulant at high pH levels, it seemed desirable to obtain some information on the rate of reversion of the complex phosphates to the ortho form in sewage. Results of studies at 5° and 20° C. (Figure 7) show that reversion is hindered materially at low temperatures and that the TPP is hydrolyzed much more slowly than TSPP. Therefore, coagulation with sodium aluminate at high levels of pH should be avoided unless hydrolysis of the

complex phosphates has proceeded essentially to completion.

Discussion

This paper has attempted to show that current and expected future use of synthetic detergents constitutes a serious increase in fertilization by phosphorus of aquatic areas receiving domestic sewage. The trend in use of such detergents rich in phosphorus cannot be reversed for numerous reasons. It, therefore, becomes the responsibility of those interested in preservation of aquatic areas to tackle the problem on the receiving end, so to speak.

The control of algal growths, both suspended and rooted, has been attempted in a number of ways. Rooted vegetative forms are usually trimmed off with an underwater cutter or poisoned by the application of some chemical, such as sodium arsenite. In either case the cuttings serve to "manure" the waters as they die and undergo decay. The control of suspended algal growths has most often been accomplished by treatment with copper sulfate. Here again the crop of algae killed remains in the water and sinks to the bottom, where it undergoes decomposition with release of much of the fertilizing elements it originally contained. Such practices are not only expensive and rather unreliable, because they are dependent upon man for execution, but also none of them strikes at the root of the trouble.

Application of the principle of Liebig's Law of the Minimum to control of undesirable aquatic growths would seem to be a scientific approach to the problem. The removal of phosphates from domestic sewage and other wastes rich in phosphorus appears to offer real possibilities. The question naturally arises concerning the critical level of phosphorus which may be allowed without danger of supporting undesirable growths. The author has suggested a limiting value of 0.01 p.p.m. of inorganic phophorus based upon his observations on 17 Wisconsin lakes. This value may be too great for some lakes and perhaps well below the limit for others.

One of the most important factors which will determine critical nutrient levels is that of lake area. Correlated items are morphology and direction of the prevailing winds during the active growing season. The most obnoxious conditions produced by algae are those which result from concentration of floating forms under the impetus of a gentle breeze with deposition on the leeward shoreline. Such accumulations, often several inches thick and extending several feet from shore, in the heat of a warm summer sun die, decay, and emit odors that will dampen the spirits of the most ardent recreationist in the area. Thus, it would seem that the tolerable level of a nutrient element such as phosphorus will vary inversely as the area of the body of water or the expanse exposed to wind action.

Until such time as more information exists, it would seem wise to reduce the level of the element chosen to be the limiting one to concentrations comparable to those of the natural drainage waters of the area.

Summary

1. Estimates based on current consumption of phosphates in the formulation of synthetic detergents and water softeners indicate that the average content of phosphorus in domestic sewage has doubled in the past six years. Because of this factor, smaller amounts of domestic sewage will cause undue fertilization of aquatic areas than formerly was the case.

2. Removal of phosphates from sewage by biological or chemical means appears to be a practical way of limiting algal growths in accordance with Liebig's Law of the Minimum.

3. Chemical coagulation with lime,

ferric, or aluminum salts will effectively remove all forms of phosphates from solution.

4. Sodium aluminate will coagulate all forms of the phosphates at pH levels below 8.0, but is ineffective in the range of 8.6 to 10.2. At pH levels above 10.2 it will remove orthophosphate; however, it is relatively ineffective in removing the complex phosphates.

5. The complex phosphates, especially TPP and Calgon, revert very slowly to orthophosphate in sewage.

Acknowledgment

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VIABILITY OF COLIFORM ORGANISMS IN ESTUARY WATER

By T. C. Buck, Jr., C. E. Keefer, and Hester Hatch

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Although the presence of coliform organisms in watercourses has long been recognized as an index of pollution and the viability of these organisms in river, tap, and sea water has received the attention of many investigators, the writers know of no published data dealing with the viability of coliform organisms in estuary water stored in the laboratory. Three series of laboratory experiments, which were conducted for a period of over two years, indicate that these organisms persisted in estuary water during one group of experiments for 439 days in 1-ml. portions and during a subsequent group of experiments for 293 days in 1-ml. portions, for 382 days in 10-ml. portions and for 450 days in 30-ml. portions.

Viability in River Water

Extensive studies have been made of the death rate of bacteria in a number of rivers including the Ohio (1)(2)(3), the upper Mississippi (4), and the Illinois (5)(6). These investigations indicate, in general, that there is an increase in bacterial counts for a short period subsequent to the discharge of polluted waters into a stream. This increase is then followed by a diminishing rate of bacterial decrease. A mathematical analysis of typical bacterial changes in polluted river water has been made by Streeter (7). Butterfield (8) studied the bacterial death rate in samples of Ohio River water stored in the laboratory for 40 days at 20° C., as compared with the death rate in the river itself. The death rate was considerably more marked in the river than in the stored samples.

The viability of coliform organisms in Thames River water, well water, distilled water, and mixtures of Thames River water and distilled water, was investigated by the Metropolitan Water Board of London, England (9). The naturally occurring and cultivated coliform organisms in raw and filtered Thames River water were observed to die off rapidly. When the abovementioned water was boiled or candle filtered and then inoculated with coliform organisms, they lived for only a short time. However, when well water was boiled and then inoculated with coliform organisms, they were recoverable for periods varying from 30 to 50 weeks.

Furthermore, coliform organisms persisted for 24 weeks in Thames River water, and in various mixtures of Thames River water and distilled water that had been boiled and then inoculated with *B. coli*. In no case did growth of native coli flora or of any inoculum of a cultivated coliform occur in natural water, raw river water, or works-filtered water. Boiling destroyed living organisms, modified bacteriolytic and toxic agents, altered the chemical composition of organic matter, and apparently increased the availability of food for bacterial growth. Hydrolysis following boiling possibly led to the breakdown of complex proteins and carbohydrates with the production of more assimi-

lable substances, which supported the growth of coliform organisms.

Bigger (10) has reported on extensive laboratory experiments involving the growth of coliform bacilli in tap water at Dublin, Ireland. Samples of water were autoclaved, inoculated with *E. coli* and stored in the dark at 37°, 22°, and at room temperature (11° to 23° C.) The organisms died off within 38 days at 37° C., within 263 days at 22° C., and within 375 days at room temperature. In each of these samples there were decreases in growth, which were followed by subsequent increases. There were as many as four waves of growth. Bigger believed these waves of growth were due to the alternate accumulation and dissipation of inhibitory substances, one of which was probably carbon dioxide. Raw Dublin water was found to be unsuitable for the culture of coliform organisms. This condition was believed to be caused by inhibitory substances, presumably of a gaseous or volatile nature.

Viability in Sea Water

Numerous investigations have been made of the viability of coliform organisms in sea water. Various explanations have been postulated as to the cause of the low number of these organisms in the sea. These explanations have included the effects of bacteriophage (11), the action of sunlight (12), the presence of predators (13), the sedimentation and absorption of bacteria by marine sediment (14) (15), the presence of toxic substances (16), and the bactericidal action of sea water (17). Vacarro *et al.* (18) have concluded that "the most probable cause of the death of *E. coli* populations in sea water is an antibiotic action which requires the presence of the normal marine flora." The investigations of Ketchum, Carey, and Briggs (19) indicated that the rapid disappearance of coliform organisms in normal sea water under laboratory conditions was due to lethal factors or substances, which were apparently organic in nature and heat labile.

Preliminary Experiments

Three groups of laboratory experiments were conducted to determine the viability of coliform organisms in estuary water. The first two of these were of a preliminary nature and will be discussed only briefly. The third, which was more extensive in scope, will be discussed in considerable detail.

All of the samples of water were collected from Back River. This stream, which has a drainage area of approximately 48 sq. mi. above the sampling point and a tidal range of 1.2 ft., empties into the upper part of Chesapeake Bay east of Baltimore, Md. The oxidized effluent from the Back River sewage treatment works, which serves the major part of Baltimore, discharges into Back River. This discharge amounts to approximately 90 m.g.d. It is chlorinated each year from April 15 to September 15.

Experiment No. I

The first group of experiments was started on June 1, 1949, (Table I) and terminated on November 28, 1949, covering a period of 181 days. This six-month experiment indicated that the coliform organisms (*E. coli* and *A. aerogenes*) were still viable after this period of time.

A sample of Back River water was autoclaved and, after being divided into 100-ml. portions, was put into six sterilized, cotton-stoppered pyrex bottles. Furthermore, a like quantity of autoclaved tap water was put into two

TABLE I.—Dates of Viability Experiments

Experiment Number	Dates		Duration (days)
	Begun	Ended	
1	June 1, 1949	Nov. 28, 1949	181
2	Mar. 3, 1950	June 12, 1951	467
3	July 26, 1950	Oct. 19, 1951	450

similar bottles. Each of three bottles of the river water and one bottle of tap water were seeded with approximately 10,000 *E. coli*. Each of the other four bottles of water was seeded with the same number of *A. aerogenes* (20). The bottles were stored in the laboratory at room temperature away from sunlight. One-milliliter samples were taken from each of the eight bottles and inoculated into brilliant-green lactose bile broth (21)(22). Dilutions were made up to and including 1:0.000001. All tubes were then incubated at 35°C. for 48 hr. Portions from all eight bottles were examined bacteriologically once a month until the original samples were exhausted. Positive controls were made with each determination. A rather rapid dying off of both groups of organisms occurred after the second month. Subsequent increases and decreases were observed until the experiment terminated.

Experiment No. II

The second group of experiments was started on March 3, 1950, (Table I) and concluded on September 12, 1951. Practically the same procedures were followed as in Experiment No. I, except that 1-gal. portions of Back River water were autoclaved at 124° C. for 30 min. Tests were made for sterility, both anaerobically and aerobically. The autoclaved Back River water was put into two bottles, one of which was inoculated with *E. coli* and the other with *A. aerogenes*, type 1, and the autoclaved tap water was also put into two bottles and inoculated the same as the Back River water.

The initial inoculation was between 10,000 and 20,000 organisms per ml. The population of *A. aerogenes* increased to well over 1,000,000 (Table II) during the first few months. After the fifth month the organisms were still viable, the number being approximately the same as the original inoculation. Two months later they had increased to over 60,000 per ml. After this a gradual decrease followed by a slight increase occurred until negative results were finally obtained on June 12, 1951. A similar condition was also observed with the *E. coli*.

TABLE II.—*E. coli* and *A. aerogenes* in Autoclaved Estuary Water and Tap Water (M.P.N. in Thousands per Ml.)

Time (days)	Estuary Water[1]		Tap Water[1]	
	E. coli	*A. aerogenes*	*E. coli*	*A. aerogenes*
1	12	18	—	—
3	32	37	—	—
4	3,000	15	—	—
5	2,500	60	—	—
10	—	—	18	22
18	2,600	620	100	150
25	1,800	300	150	140
33	730	110	180	100
40	415	57	228	203
48	350	230	190	160
55	200	8	170	260
62	135	110	160	150
75	69	29	130	190
98	30	5	110	1,400
133	10	2	70	120
175	2.8	5.5	5	81
203	63	12	10	116
238	13	11	3	95
263	10	8	5	7
291	25	33	19	11
312	34	41	28	14
341	4	5	4	6
373	1.6	0.3	3.1	1.6
410	3.6	0.04	2.1	1.6
439	0.9	0.00	0.00	5.2
467	0.00	0.00	0.00	0.00

[1] Autoclaved and inoculated.

The tap water inoculated with these organisms presented a similar pattern, but their populations were never quite so high as those obtained in Experiment No. I.

Experiment No. III

An adequate quantity of Back River water was collected to make the necessary tests included in Experiment No. III. A 1-gal. portion of this water was placed into each of two 1-gal. bottles, as indicated in Table III. The water in one of these bottles (Number 1) was not aerated, whereas the water

Table III.—Outline of Treatment Given Samples of Water

I. Unautoclaved river water:
  Bottle No. 1—Unaerated.
  Bottle No. 2—Aerated (10 min. daily).
II. Autoclaved river water:
  A. Unaerated:
    Bottle No. 3—*E. coli* added.
    Bottle No. 4—*A. aerogenes* added.
  B. Aerated (10 min. daily):
    Bottle No. 5—*E. coli* added.
    Bottle No. 6—*A. aerogenes* added.
III. Distilled water:
  A. Unaerated:
    Bottle No. 7—*E. coli* added.
    Bottle No. 8—*A. aerogenes* added.
  B. Aerated (10 min. daily):
    Bottle No. 9—*E. coli* added.
    Bottle No. 10—*A. aerogenes* added.

in the other bottle (Number 2) was aerated 10 min. each day. An additional portion of the river water was autoclaved at 128° C. for 30 min. and tested both aerobically and anaerobically for sterility. A 1-gal. portion of this water was then put into each of four 1-gal. bottles. Two of these bottles (Numbers 3 and 5) were inoculated with *E. coli*, type 1, and the other two (Numbers 4 and 6) with *A. aerogenes*, type 1 (23). Two of the bottles, one containing *E. coli* and the other containing *A. aerogenes* were not aerated, whereas the water in the other two bottles was aerated 10 min. daily.

A 1-gal. portion of distilled water was placed in each of four 1-gal. bottles. The water in two of the bottles (Numbers 7 and 9) was inoculated with *E. coli*, and the other two bottles (Numbers 8 and 10) were inoculated with *A. aerogenes*. Two of the bottles that contained *E. coli* and *A. aerogenes* were not aerated and the other two were aerated.

The above-mentioned organisms were obtained in the following manner. Two strains of *E. coli* and *A. aerogenes* were submitted to a number of biochemical tests (24) (25) (26), particularly those given in "Report No. 71" of the British Ministry of Health Committee. After obtaining pure cultures, large agar slopes were inoculated, and the resulting growths were used to seed the autoclaved river water and the distilled water.

All of the aerated bottles were fitted with sterile cinder block aerators. Before entering the bottles, the air passed through a 0.1 per cent Roccal solution. The ten 1-gal. bottles, which were fitted with screw caps, were stored in the laboratory at room temperature away from direct sunlight.

Method of Conducting Experiment

Once a week for four weeks and once a month thereafter samples were drawn from each bottle and coliform tests were run in triplicate. Each bottle was shaken 25 to 30 times before a sample was withdrawn to obtain thorough mixing and 1 ml. was placed in 9 ml. of sterile distilled water for a 1 to 10 dilution. One milliliter of samples was placed in each of three tubes of brilliant-green lactose bile broth. The 1 to 10 dilution bottle was shaken 25 to 30 times, and 1 ml. was transferred to another dilution bottle containing 9 ml. of sterile distilled water, making a 1 to 100 dilution. One ml. of the 1 to 10 dilution was placed in each of three tubes of brilliant-green lactose bile broth. This procedure was carried out until a final dilution of 1 to 0.000000001 was reached, and three tubes of brilliant-green lactose bile broth were inoculated for each dilution.

The brilliant-green lactose bile broth was then incubated at 37° C. for 48 hr. After 48 hr. of incubation the tubes were read and recorded as plus or minus for gas production. A loopful of culture from each positive tube was transferred to Koser's citrate medium, and another loopful was transferred to brilliant-green lactose bile broth.

TABLE IV.—E. coli and I.A.C. Organisms in Unautoclaved and Autoclaved Estuary Water and in Distilled Water (M.P.N. in Thousands per Ml.)[1]

Time (days)	Estuary Water								Distilled Water			
	Unautoclaved				Autoclaved and Inoculated				Autoclaved and Inoculated			
	Unaerated		Aerated[2]		Unaerated		Aerated[2]		Unaerated		Aerated[2]	
	E. coli (Bottle 1)	I.A.C. (Bottle 1)	*E. coli* (Bottle 2)	I.A.C. (Bottle 2)	*E. coli* (Bottle 3)	*A. aerogenes* (Bottle 4)	*E. coli* (Bottle 5)	*A. aerogenes* (Bottle 6)	*E. coli* (Bottle 7)	*A. aerogenes* (Bottle 8)	*E. coli* (Bottle 9)	*A. aerogenes* (Bottle 10)
1	2.5	2.5	2.5	2.5	175,000	25,000	2,500	2,500	1,000	925	0.175	1.75
7	0.25	0.25	17.5	17.5	2,500	100,000	2,500	17,500	250	2,500	0.25	250
15	1.0	1.0	0.25	0.25	2,500	2,500	250	1,000	25	1,000	0.025	1,000
20	2.5	0.25	1.0	1.0	2,500	2,500	250	1,000	25	25,000	2.5	1,000
47	1.75	1.75	17.5	17.5	2,500	10,000	25	2,500	1,000	250	0.25	100
77	0.25	0.25	0.25	0.25	10,000	250	1.0	92.5	25	10	0.025	0.025
108	0.25	0.25	1.75	1.75	175	250	100	25	25	25	1.75	0.25
138	2.5	2.5	2.5	2.5	2.5	250	1.75	17.5	250	17.5	0.025	0.25
166	1.75	1.75	0.25	0.25	0.025	10	0.25	2.5	250	1.75	0.3025	0.025
194	1.75	1.75	0.025	0.025	0.175	110	0.175	0.25	2.5	0.175	0	0.0025
222	0.025	0.025	0.025	0.025	0.0025	1.0	0.175	0.25	0.25	0.10	0	0.0025
258	0	0.0025	0	0	0.0025	0	0.0025	0	0.025	0	0	0
293	0	0.025	0	0	0	0.025	0	0	0	0.0025	0	0.025
319	0	0	0	0	0	0	0	0	0	0	0	0
355	0	0	0	0	0	0	0	0	0	0	0	0
382[3]	0	0	0	0	0	0	0	0	0	0	0	0
450[4]	+	+	+	+	+	+	−	−	−	−	−	−

[1] Averages of three determinations; Wilson's method of expressing results used.
[2] 10 min. daily.
[3] Used 10-ml. portions.
[4] Used 30-ml. portions.

TABLE V.—pH of Estuary Water and Distilled Water

Time (days)	Estuary Water						Distilled Water			
	Unautoclaved		Autoclaved and Inoculated				Autoclaved and Inoculated			
			Unaerated		Aerated[1]		Unaerated		Aerated[1]	
	Unaerated (Bottle 1)	Aerated[1] (Bottle 2)	*E. coli* (Bottle 3)	*A. aerogenes* (Bottle 4)	*E. coli* (Bottle 5)	*A. aerogenes* (Bottle 6)	*E. coli* (Bottle 7)	*A. aerogenes* (Bottle 8)	*E. coli* (Bottle 9)	*A. aerogenes* (Bottle 10)
0	7.90	7.90	7.82	7.82	7.82	7.82	7.30	7.30	7.30	7.30
293	8.61	8.30	8.30	8.40	8.30	8.30	8.20	8.20	8.10	8.30

[1] 10 min. daily.

The citrate cultures were incubated at 37° C. and the brilliant-green lactose bile broth at 44° C. for 48 hr. At the end of 48 hr. the citrate cultures were observed for carbon utilization, which was indicative of intermediate-aerogenes-cloacae (I.A.C.) organisms. The brilliant-green lactose bile broth cultures were read and recorded as plus or minus for gas production, plus being indicative of *E. coli*.

Results

The *E. coli* and the I.A.C. organisms survived for periods varying from 166 to 293 days (Table IV) as determined by the examination of 1-ml. portions. In general, the I.A.C. organisms lived for longer periods of time and in some of the bottles were present in greater numbers than the *E. coli* organisms.

Although there was a gradual decrease in the number of organisms with the lapse of time, in some instances the number decreased and then later increased in successive waves. For example, the number of *E. coli* in bottle 7, which contained unaerated distilled water inoculated with these organisms, decreased in 20 days from a count of 1,000,000 per ml. to 25,000, then increased to 1,000,000 at the end of 47 days, decreased at a later date to 25,000, increased again to 250,000, and at the end of 293 days were not found in 1-ml. samples.

Aerating the samples had little effect on the viability of the organisms.

In general the organisms lived for approximately the same period of time in unautoclaved estuary water, in inoculated autoclaved estuary water and in inoculated distilled water.

There was in increase in the pH value (Table V) of the contents of each of the bottles. For example, the pH value of the unaerated, unautoclaved estuary river water increased from 7.9 at the beginning of the observations to 8.61 at the end of the study, 293 days later. This increase in pH may have been due to the formation of ammonia in the bottles.

At the beginning of the experiment the necessary biochemical tests were made to identify the strain of organisms used to inoculate the estuary and the tap water. Similar tests made at the end of the experiment indicated that no change in the strain or organisms had occurred.

Discussion and Conclusions

It should be emphasized that laboratory conditions are vastly different from those occurring in nature. Any interpretation of the results of such laboratory studies should be made with extreme caution.

Both the *E. coli* and the I.A.C. organisms were present for much longer periods of time than was originally anticipated. The investigations confirmed some of the observations made by the Metropolitan Water Board of London (9) and by Bigger (10).

Estuary water, both autoclaved and unautoclaved, when retained in the laboratory was capable of supporting coliform organisms for a prolonged period of time. This same statement applied to distilled water that was inoculated with these organisms.

If it is assumed that conditions in the field are in general similar to those in the laboratory, it would seem reasonable to expect that coliform organisms, once introduced into an estuary, would be present for long periods of time provided their number was not reduced by such factors as sedimentation, predatory protozoa, excessive acidity or alkalinity, or various toxic compounds.

The fact that a decrease in the number of *E. coli* and I.A.C. organisms was followed in several instances by an increase in number is of interest. This cycle, involving a decrease and then a subsequent increase in numbers, occurred at least twice in several of the bottles. It is believed that as the bacteria died off, the protoplasm of their cells served as a source of nutriment for the surviving organisms, which then increased in numbers. As a rule, the maximum concentration of organisms in successive cycles gradually became less. Finally the number of organisms decreased to such a degree that they were not found in either 1-, 10- or 30-ml. portions. It is believed that the eventual decrease in the number of organisms in all of the samples was probably due, at least in part, to the formation of toxic compounds, to a decrease in food supply, or to a combination of these two factors. It is definitely known that when coliform organisms grow on a number of media, they produce toxic substances that result in the death of the organisms. Similar toxic substances may have been produced in the ten water samples under investigation.

A decrease in the food supply for sustaining the life cycle of the surviving cells seems apparent, as the protoplasm of the dead cells, which consisted in part of carbohydrates, fats, and protein, was converted through a system of complicated biochemical reactions into carbon dioxide, hydrogen, ammonia, water, and other compounds. These materials could not be re-used as a source of food supply by the coliform organisms.

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R. J. Trautman, principal associate engineer, has direct supervision of the sewage works and Paul L. Smith, is plant superintendent.

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THE OPERATOR'S CORNER

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SLUDGE DISPOSAL EXPERIENCES AT ELIZABETH, N. J.*

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The complete and satisfactory disposal of the solid by-products of sewage treatment long has been, and still is for that matter, one of the more difficult and costly phases of sewage treatment. The method adopted usually depends upon the size of the treatment plant, its location and, to a lesser extent, the type of treatment given. Briefly reviewed, the following methods of sludge disposal commonly are practiced at plants in this country:

1. In treatment plants embodying sludge digestion, the digested sludge is processed by vacuum filtration or air drying and finally is disposed of by incineration, conversion into fertilizer ingredients, or spread upon the land.

2. In treatment plants not including sludge digestion, the raw sludge is disposed of by vacuum filtration and incineration, or occasionally by lagooning, or by discharge directly into the ocean.

3. In a few cases large plants situated near the ocean are able to dispose of their raw primary or activated sludges in the liquid state by barging them to a designated point at sea and discharging them under controlled conditions.

The Elizabeth Joint Meeting plant is one of the three users of the last method in the Port of New York area and during the past 15 yr. has had many interesting and profitable experiences in the handling of raw sludge. It has met and solved many problems of concentration, storage, and pumping. It has learned much about the characteristics and behavior of raw sludge within the temperature range 45° to 75° F. and has built up a complete record of them during some 365 barge loadings averaging more than 3,400 tons each, or a gross total of more than 1,250,000 tons.

It is not the purpose of this paper to go into a detailed technical discourse on the collection and pumping of raw sludge, its concentration by flotation, the methods used at the Elizabeth plant for conditioning the sludge prior to loading into barges, viscosity, pumping problems, or disposal at sea—each of which is a subject complete in itself—but rather to touch lightly upon some typical problems as they were encountered from time to time during operation.

Twenty years ago, at the time the plant was being built, disposal of sludge at sea in the New York area was being practiced only by the Passaic Valley Sewerage Commission. It was natural that this method, as

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well as all the other known methods of sludge disposal, was considered by the Joint Meeting in the design of the plant.

The method of disposal at sea was adopted by the Joint Meeting in preference to all others, and operation of the plant finally began in March, 1937. Since that time, the City of New York has joined with Passaic Valley and with the Joint Meeting in using this method.

Description of Treatment Plant

The Elizabeth Joint Meeting plant is the jointly operated sewage treatment works serving 12 municipalities in Essex and Union Counties, N. J. In general, the area served may be described as that lying to the west and south of Newark in the drainage areas of the Elizabeth and Rahway Rivers. The present population contributing to the plant is about 400,000.

The plant is located in the southeastern or Bay Way section of Elizabeth, near the Goethals Bridge, approximately ¼ mi. inland from the Arthur Kill, which separates New Jersey and Staten Island, upon a site approximately 28 acres in area.

Sewage enters the plant through twin influent sewers with a capacity of 172 m.g.d. and flows through the various channels and settling tanks to the outfall sewers and eventual discharge in the Kill entirely by gravity. No pumping of the sewage is necessary beyond that which might be required for dewatering tanks for repair, or odor prevention. Screenings are collected mechanically, shredded in a screenings grinder, and returned to the sewage to be collected with the raw primary sludge. Grit is mechanically collected, washed, and pneumatically ejected to the adjacent meadowland, where it is used for fill. Raw primary sludge is collected mechanically, pumped to concrete storage tanks, concentrated by flotation, and periodically pumped to tank barges at the waterfront and barged to a point at sea for final disposal. All sludge handling is done by pumps, the fresh sludge being placed in storage by duplex plunger-type pumps and the concentrated sludge removed from storage to the barge by centrifugal pumps.

Early Sludge Pumping Experiences

The period of tune-up in a sewage treatment plant brings many "headaches" to engineers and operators alike. The Elizabeth plant was no exception to the rule. However, the author rather enjoyed them, for the nice thing about a "headache" or any other pain is that it feels so good when it stops.

Arrangements were made for the first trip to sea the afternoon of May 9, 1937, at which time the two storage tanks held nearly 4,000 tons of sludge. A representative of the barging contractor had been at the dock the previous day to check all the details preliminary to the docking, even so far as to taking depth soundings, and had found everything to be in order.

Indications were that the quantity of sludge to be barged would fall short of the original estimates, the rate of production indicating that the frequency of trips would be from 20 to 30 days. It was very interesting to note that 80,000 g.p.d. of sludge averaging 93 to 97 per cent moisture was being collected from the settling tanks, but only 20,000 g.p.d. (less than 100 tons) having a moisture content from 85 to 90 per cent was being accumulated in storage.

In sludge concentration, the procedure of alternating between the storage tanks, decanting from the tank out of service, was being followed. This permitted a minimum of agitation and much better supernatant drawoff. Only 25 per cent of the sludge as originally pumped remained in the tanks as sludge to be barged, the 75 per cent going back to the influent sewage.

In view of the thickness of the sludge held in the storage tanks, some anxiety was felt about making a successful loading of the sludge in order to have performed all of the principal functions of the treatment process before such time as a shortage of storage tank capacity might tie up operations in case of the "unexpected." But what happened? On May 9 the first trip was scheduled and everything was thought to have been in readiness. The loading was started, and for the first hour everything seemed to be all right. Then the sludge stopped coming through the pipes. Water was added at the pumps to thin out the sludge. Tanks were alternated to try to find out what was wrong. All to no avail. Being under pressure of a 5-hr. time limitation in loading, there was no opportunity to survey the pipeline and equipment to find out what was wrong. The final result was that in 6½ hr. 1,400 tons were loaded, instead of the 3,000 tons in 5 hr. planned in design.

A careful study was made of the 4,400-ft. long force main, and a pressure gage was installed in the flushing control chamber about half-way along the line. Provision also was made at this point, in the event that the sludge line became clogged during the pumping when time was all-important, to use compressed air to break it through. May 15 was set for another try, as accumulation of sludge was now approaching critical proportions.

As before, the first hour went fine, and then the flow stopped. Air was blown through the line until the gages showed no pressure. Still, little more than a trickle of flow was obtained, although the combination of pumping and compressed air was tried repeatedly. Work was continued through the night, regardless of the time limit, until 4 AM, when the tide made the barge cast off. This time 2,100 tons of sludge was loaded in 12 hr. pumping time, still a long way from the required rate of 3,000 tons in 5 hr.

It seemed strange that for a while sludge would come through and then stop so completely. At one time during the construction of the force main, some planks had been observed in the pipe prior to the installation of pumping equipment and fittings in the siphon chamber. Acting on the hunch that they might have been forgotten and that this might be a possible cause, the piping was opened up. Sure enough, a nice 3-in. by 10-in. plank was wedged into the plug valve. After considerable time the plank was cut up bit by bit with chisels and withdrawn through the valve opening.

At none of the early bargings was it hoped to ever load the 3,000-ton requirement in 5 hr. On June 3 explorations of the pipeline turned up 25 ft. of garden hose. However, as the weather became warmer so did the sludge. The heads due to friction decreased and the rates of pumping increased. Many ideas were developed as time went by. It was necessary over the years to make many changes in the piping arrangement, to change to larger pumps and larger motors, and to introduce many changes in operating procedures—all of which now results in relatively predictable loading operations.

Obviously, the first headaches in operation were caused by producing a sludge so dense and viscous it could not be pumped the 4,400-ft. distance to the dock for loading in the prescribed loading period with the equipment provided. Experiments were begun in the direction of "conditioning" the sludge in storage immediately before the loading was to begin. First, water was introduced with fire hoses, giving encouraging results. However, there were the objections of increasing the volume of material to be barged and the cost of the water used. A method was then devised for com-

pletely mixing the contents of the storage tanks by recirculating, and a means was created of pumping sewage into the sludge mass when needed as a means of controlling the moisture content of the material as it flowed to the sludge pumps. Present practice is to recirculate from 2 to 4 hr. before loadings are scheduled to begin, and add sewage jetted under pressure when the rate of pumping falls below 400 tons per hour.

The fastest loading which is representative occurred July 26, 1951, during which 3,380 tons of sludge was loaded into the barge in 2 hr. 35 min. The average solids content was 8.35 per cent and the temperature 74° F.

During present operation it seldom requires more than 6 hr. to complete a loading, whether summer or winter, with the average solids content of the sludge as barged over the entire yearly period running about 8.75 per cent.

The First Winter

During the barge loading of December 14, 1947, the first sample of what cold weather once meant to the operations occurred. The barge had docked, the hoses were connected. What happened? At the dock both of the main plug valves were frozen and required dismantling of the hoses and elbows and the liberal application of hot water to the valves and the loosening of all bolts holding the same before they finally could be opened. After the valves were opened, frozen sludge remaining in the pipe, particularly in the open section of piping under the dock above the water, created so much resistance that the pumps were unable to force the sludge through the main from the storage tanks to the barge. It required 30 lb. of air pressure to open the line before the pumps were able to deliver appreciably. When finally started, at 2 PM, the rate of pumping was slow—and this particular load finally was 600 tons short, because of tide limitations.

This time, however, something else was added in the way of another "headache"; the freezing of sludge against the tank walls and the damage that this was liable to cause to the floating tank covers during the withdrawal of sludge from storage. As the covers began to fall sludge was seen coming through the annular space between the covers and the walls like toothpaste, particularly on the north and west sides of the storage tanks. Close inspection indicated that it was frozen right against the walls, and it became necessary to put men equipped with picks and shovels on the covers of each tank to peel the sludge off the walls and watch for possible binding or jamming of the covers in the event that the thickness of ice should prevent the covers from dropping evenly. Fortunately, the thickness was just enough to permit the covers to come down, or it would have been necessary to stop the loading until proper steps could have been taken to protect the covers.

The main worry was over the possibility of unbalanced descent of the floating covers resulting in jamming the covers and causing damage to them. The manufacturers were consulted. They had no knowledge as to where installations similar to this one had been made under such conditions. It is the usual thing for tanks with floating covers to be used as digesters and, as digesters, to be insulated and provided with heating coils to develop and maintain temperatures of from 85° to 95° F. Freezing in that case would be limited to just the space between the cover and the wall and can more or less be controlled with rock salt or oil. This would not be a feasible method of control for our problems.

The method that suggested itself as the only feasible solution was to float the covers to the tops of the walls, extend the trusses to bear uniformly on top of them, and then to regulate the height of material placed in the

tanks thereafter so as not to lift the covers off their fixed positions. This was done and the covers have been resting on top of each storage tank ever since.

Sludge Force Main Break

On March 23, 1948, shortly after beginning to pump sludge to the barge during loading No. 262, a telephone call was received from one of the industrial plants between the treatment plant and the dock that sludge was coming up through the ground in front of their building.

Pumping was stopped and an investigation made. There was the sludge all right, spread all over their lawn and flower beds. The records indicated that at the time the sludge came up through the ground, there was a pressure on the force main of some 80 ft. of head, or about 35 lb. per sq. in. The sludge was very dense.

There was no question about there being a break in the 24-in. diameter steel force main nearby. The barge had just begun to take on its load and the two storage tanks were almost full of sludge, which had to be disposed of. The question was: "What do do?" Examination of the record drawings showed the pipe to be of 24-in. diameter steel, laid in 40-ft. lengths, and joined by means of Dresser couplings. It was laid about 12 ft. back of the curb line and was about 10 ft. below the surface.

It was decided to dilute the sludge with sewage at the maximum rate to reduce head conditions and pressure in the line as much as possible, and to resume pumping to get storage space at the plant, as well as to load the barge. A watchman was placed near the break throughout the entire loading period to give notification by telephone in case the leak began to get out of hand. Fortunately it was possible to reduce pressures about 50 per cent and no evidence of increased leakage appeared during the rest of the loading.

The next day digging was begun to find the leak. Ground conditions were very bad. The pipe was below the tide level and in quicksand. Fortunately, the sheathing driven during construction was intact, and with the help of pumps it was possible to excavate inside of it down to the pipe in about two days. The next thing was to find the hole. As there are now no valves on the discharge end of the force main, some means had to be contrived of closing the end to hold pressure without leaking at the dock. This was accomplished by removing the hoses and putting on 12-in. diameter blank flanges. When these were in place sewage was put into the force main, a little air pressure was released behind it, and the pipe was watched to see what would happen. The water soon began to run into the open trench from a southerly direction. Digging in that direction revealed the source of difficulty—a hole about ¾ in. by 1½ in. and irregular in shape. The pipe was steel, enameled on the inside and coated with a protective covering on the outside, and had a wall thickness of about ¼ in. The pipe in the vicinity of the hole appeared to be in perfect condition, excepting for an area about 3 in. square right at the hole. At this point the coating was gone and the pipe appeared to be slightly dented, as if the pipe had been struck by the tooth of a clamshell bucket. There was no evidence of rust and the edges of the hole were of full thickness, evidence that perhaps the damage was direct and physical rather than corrosive in nature.

Because of the large size of the pipe, a suitable repair sleeve was not conveniently obtainable. Therefore, because the hole was small the repairs were made by plant personnel. A piece of steel plate curved to fit the outside of the pipe, a sheet of rubber gasket material, some bronze cable, cable clamps, and a few steel wedges

were all that were needed. After the patch had been placed water was again pumped into the line at the highest internal pressure obtainable. No further trace of leakage was found. More than 100 barge loadings have been made since then and no further signs of trouble have been found at this spot.

These experiences and many others involving strikes, storms, water traffic, and shallow water to mention a few, have been met and overcome. Under the contract the barging contractor has to provide two barges, which are to be available for service at all times, in the event that one is disabled or sunk. The latter situation never has occurred to interfere with the Elizabeth plant's schedule; but it did occur in 1935, when the "Brooklyn," which then was being used by Passaic Valley, was rammed in Kill Von Kull between Bayonne and Staten Island, and sank in about 3 min. Its successor, the good ship "Carryall," is still in service and now is being used by the Elizabeth plant.

1952 REPORT—COMMITTEE ON QUALIFICATIONS OF SEWAGE WORKS OPERATORS

The Federation of Sewage and Industrial Wastes Associations' standing committee on "Qualifications of Sewage Works Operators" again circularized the state sanitary engineers on December 5, 1951, relative to the current status by states of operators' certification plans now in effect or under consideration. In states having plans in effect, copies of local regulations were received in most cases, and these have been placed on file in the headquarters office of the Federation for the information of members.

The previous inquiry to the states was on February 20, 1947, and the committee's report was published in THIS JOURNAL, January, 1948, page 137. Replies were received at that time from 42 of the 48 states, whereas all the states, Hawaii, and three foreign associations of the Federation replied to the current survey.

The recommendations for state operators' certification plans were submitted by this committee to the Federation's membership in its report published in THIS JOURNAL, January, 1946, page 147.

Because of the continued interest in operators' certification plans, the committee is pleased to present (Table I) a summary of the replies received from the state sanitary engineers and others, whose cooperation is hereby acknowledged with thanks.

Certification plans are in effect in 16 states, of which 9 have voluntary plans and 7 required plans. Certification plans are being considered in 14 states, of which 10 may be voluntary, 3 required, and 1 is undecided. The current survey indicates an increase of 4 states having plans in effect as compared with the 1947 survey. Of these 4 states, two have placed required plans in effect. There is also an increase of 3 states considering a plan during the past 5-year period. A number of the states reporting a plan under consideration in 1947 have not yet placed one in operation.

Summary

This survey indicates a continuing growth in the states adopting or considering a certification plan. The committee urges all states to embark on a required certification plan as an assurance of competent operation for the many sewage treatment plants now in

TABLE I.—Summary of 1951 Status of Sewage Plant Operators' Certification and Licensing Plans

State	Plan in Effect	Date Started	Plan Being Considered	Voluntary or Required	Periodic Renewal of Certificate Required	Any Grandfather Clause?	Name of Agency Administering Plan	How Many Classes of Operators?	Exams. Given?		Remarks
									Oral	Written	
Alabama	No	—	Yes	Voluntary	—	—	—	—	—	—	Committee of Alabama Water & Sewage Assn. formulating a voluntary plan.
Arizona	No	—	Yes	Voluntary	—	—	Arizona Sewage & Water Works Assn.	—	—	—	Association committee working on a plan.
Arkansas	No	—	Yes	Voluntary	Yes	No	Arkansas Water & Sewage Conf.	3	No	Yes	It is expected to start this plan in 1952 or 1953.
California	Yes	1935	—	Voluntary	Every 5 yr.	No	California Sewage Works Assn.	3	No	Yes	—
Colorado	No	—	No	—	—	—	—	—	—	—	—
Connecticut	Yes	1933	—	Required	No	Yes	State Dept. of Health	None	Sometimes	No	Department reviews education and experience of each applicant with respect to type and size of plant he will operate.
Delaware	No	—	Yes	Voluntary	—	—	Maryland-Delaware Water & Sewerage Works Assn.	—	—	—	Plan under investigation.
Florida	Yes	1941	—	Voluntary	Every 3 yr.	No	Florida Water & Sewage Works Operators Assn.	3	—	—	Certificates issued by State Board of Health based on written examinations and experience data.
Georgia	Yes	1936	—	Voluntary	Yes	No	Georgia Water & Sewage Assn.	3	No	Yes	—

TABLE I (Cont.)—Summary of 1951 Status of Sewage Plant Operators' Certification and Licensing Plans

State	Plan in Effect	Date Started	Plan Being Considered	Voluntary or Required	Periodic Renewal of Certificate Required	Any Grandfather Clause?	Name of Agency Administering Plan	How Many Classes of Operators?	Exams. Given?		Remarks
									Oral	Written	
Hawaii	No	—	No	—	—	—	—	—	—	—	The small number of plants in the Territory makes possible direct and close control over operators' work.
Idaho	No	—	No	—	—	—	—	—	—	—	When state has more sewage plants, a voluntary certification program will undoubtedly be started.
Illinois	Yes	1951	—	Required	Annually	Yes	Illinois Sanitary Water Board	5 and a temporary status	Sometimes	Yes	Operators having a certificate under the previous voluntary plan are automatically certified.
Indiana	No	—	Yes	—	—	—	—	—	—	—	Regular attempts to have state legislature enact a bill requiring certification have to date failed. Certification deemed important.
Iowa	No	—	Yes	Voluntary; possibly req. later	—	—	Vol: Iowa Sewage Works Assn. Req.: State Dept. of Health	—	—	—	Bill for required licensing plan introduced in last two sessions of legislature, but bill did not reach floor. Voluntary plan in process of development during interim.
Kansas	No	—	No	—	—	—	—	—	—	—	—
Kentucky	No	—	Possibly in near future	—	—	—	—	—	—	—	State Dept. of Health can by law license operators, but this has not been done to date. A plan may be put in effect in near future.

TABLE I (Cont.)—Summary of 1951 Status of Sewage Plant Operators' Certification and Licensing Plans

State	Plan in Effect	Date Started	Plan Being Considered	Voluntary or Required	Periodic Renewal of Certificate Required	Any Grandfather Clause?	Name of Agency Administering Plan	How Many Classes of Operators?	Exams. Given?		Remarks
									Oral	Written	
Louisiana	Yes	1947	—	Voluntary	Yes	No	Louisiana Conf. on Water Supply & Sewerage	2	Yes	Yes	—
Maine	No	—	No	—	—	—	—	—	—	—	—
Maryland	No	—	No	—	—	—	—	—	—	—	Maryland-Delaware Water & Sewerage Assn. preparing report on subject for possible action.
Massachusetts	No	—	Yes	—	—	—	—	—	—	—	Short course for sewage treatment plant operators being given annually.
Michigan	Yes	1952	—	Required	No	Yes	State Dept. of Health	4	No	Yes	—
Minnesota	Pending	1952	—	Voluntary	Every 5 yr.	No	State Dept. of Health	4	Possibly	Yes	—
Mississippi	No	—	No	—	—	—	—	—	—	—	—
Missouri	No	—	Yes	Voluntary	Yes	Yes	Missouri Water & Sewerage Conf. with State Health Dept. acting as advisor	None	Yes	Yes	Tentative plan developed 3 or 4 yr. ago. A revised plan may go into effect 2 or 3 yr. hence.
Montana	No	—	No	—	—	—	—	—	—	—	When more plants are built, a plan will no doubt be considered.

TABLE I (Cont.)—Summary of 1951 Status of Sewage Plant Operators' Certification and Licensing Plans

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									Oral	Written	
Nebraska	No	—	See remarks	—	—	—	—	—	—	—	Certification plans being discussed and interest is high. No definite program as yet.
Nevada	No	—	No	—	—	—	—	—	—	—	Training programs for operators conducted by State Dept. of Health.
New Hampshire	No	—	No	—	—	—	—	—	—	—	—
New Jersey	Yes	Revised 1946	—	Required	Yes	Yes	Bureau of Examination and Licensing, N. J. State Dept. of Health	7	Yes	Yes	Original plan in New Jersey in effect in 1918.
New Mexico	No	—	Yes	Voluntary	—	—	Proposed to ask State Dept. of Public Health to administer plan	—	—	—	—
New York	Yes	1937	—	Required	No	Yes	State Dept. of Health	5	See remarks	See remarks	Public Health Council of the Department may require written, oral, or practical examinations, but this is not common practice.
North Carolina	No	—	Yes	Voluntary	—	—	—	Perhaps 3	—	—	Two schools for operators have been held; planned to develop a voluntary plan such as now in effect for water plant operators.

TABLE I (Cont.)—Summary of 1951 Status of Sewage Plant Operators' Certification and Licensing Plans

State	Plan in Effect	Date Started	Plan Being Considered	Voluntary or Required	Periodic Renewal of Certificate Required	Any Grandfather Clause?	Name of Agency Administering Plan	How Many Classes of Operators?	Exams. Given?		Remarks
									Oral	Written	
North Dakota	Yes	1940	—	Voluntary	Yes	Yes	North Dakota Water & Sewage Works Conf.	3	No	No	Certification based on qualifications and experience.
Ohio	Yes	1938	—	Required	No	Yes	Ohio Dept. of Health	3	No	Yes	—
Oklahoma	Yes	1949	—	Voluntary	Yes	No	Okla. Water, Sewage & Indus. Wastes Conf.; Com. of Health issues certification	3	For A & B grades only	Yes	—
Oregon	No	—	No	—	—	—	—	—	—	—	Nothing definitely planned, but if one is adopted it will be voluntary.
Pennsylvania	No	—	Yes	Voluntary	—	Probably	Penn. Sewage & Industrial Wastes Assn.	—	—	—	Committee now formulating details.
Rhode Island	No	—	No	—	—	—	—	—	—	—	—
South Carolina	Yes	1935	—	Voluntary	Every 5 yr.	No	South Carolina Water & Sewage Works Assn.	4	No	Yes	Association hopes to establish legal registration of both water and sewage plant operators within near future.
South Dakota	No	—	No	—	—	—	—	—	—	—	Plan considered desirable by State Dept. of Health, but no active steps have been taken to initiate such a plan.

TABLE I (Cont.)—Summary of 1951 Status of Sewage Plant Operators' Certification and Licensing Plans

State	Plan in Effect	Date Started	Plan Being Considered	Voluntary or Required	Periodic Renewal of Certificate Required	Any Grandfather Clause?	Name of Agency Administering Plan	How Many Classes of Operators?	Exams. Given?		Remarks
									Oral	Written	
Tennessee	No	—	No	—	—	—	—	—	—	—	An annual short school for operators has been started during the past 2 yr.
Texas	Yes	1945	—	Required	Yes, except for highest grade	Yes	State Dept. of Health	4	No	Yes	Voluntary plan in effect since 1937. Required certification began in 1945, when voluntary plan certificates in effect were recognized for compliance with law.
Utah	No	—	No	—	—	—	—	—	—	—	No immediate plans for action because of limited number of plants in operation.
Vermont	No	—	No	—	—	—	—	—	—	—	Small number of plants in operation has not indicated a need for certification to date.
Virginia	No	—	No	—	—	—	—	—	—	—	Virginia Industrial Wastes & Sewage Works Assn. has been discussing a certification plan, but no regulations have as yet been adopted.
Washington	Soon	Soon	—	Voluntary	No	No	Pacific Northwest Sewage and Indus. Wastes Assn.	5	Yes	Yes	Applications for certification being received now.

TABLE I (Cont.)—Summary of 1951 Status of Sewage Plant Operators' Certification and Licensing Plans

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									Oral	Written	
West Virginia	No	—	Yes	Required	—	—	—	—	—	—	Law gives state authority to require certification; certification will be required when number of plants installed increases.
Wisconsin	No	—	No	—	—	—	—	—	—	—	—
Wyoming	No	—	No	—	—	—	—	—	—	—	Annual sewage works school held.
Argentina Society of Engineers	No	—	—	—	—	—	—	—	—	—	Program for training of operators and possibly licensing was being considered before 1946 but closing of Society activities since this time has halted any action.
Province of Ontario, Canada	No	—	Yes	Voluntary	—	—	Ontario Dept. of Health	—	—	—	It is hoped to put this plan in effect soon.
Institute of Sewage Purification, England	No	—	—	—	—	—	—	—	—	—	The secretary of the Institute reports plant vacancies customarily filled by applicants holding the Institute's certificates, issued on basis of prerequisite qualifications and passing of oral and written examinations.
German Sewage Technologists Assn.	No	—	No	—	—	—	—	—	—	—	Secretary has expressed interest in subject and has requested additional information from committee.

operation or under construction. Modern sewage treatment plants are in many cases highly mechanized and require operators with mechanical aptitude and manual dexterity. The establishment of definite qualifications with legal status for plant operators is an important part of the sewage works program, without which the entire movement may be seriously handicapped.

BENJAMIN BENAS
T. C. SCHAETZLE
LEROY W. VAN KLEECK, *Chairman*
COMMITTEE ON QUALIFICATIONS OF SEWAGE WORKS OPERATORS

TIPS AND QUIPS

Not Always Like That

Employees at the new Waterbury, Conn., sewage treatment plant must have thought they had hit real pay dirt when large-denomination paper money was found in the screenings hopper recently. Of course, the three finders will not be keepers for at least six months, during which time the (literally) filthy lucre will be cached in the Police Department safe awaiting a claimant.

According to Superintendent Walter M. Kunsch, screenings at the plant will no doubt receive closer attention for some time to come, but we're afraid that the gold strike was probably just a "flash in the pan."

Municipal-Industrial Cooperation

A cooperative pilot plant project for treatment of industrial wastes received by the Borough of Middlesex, N. J., sewage treatment plant is providing data that should prove extremely valuable to both the industry and the municipality when secondary treatment facilities are estimated for the municipal works. Such a project is considered most unusual in municipal and industrial relations, although it sets a pattern that may well be followed in other cases.

Acceptance of partially treated industrial wastes in the municipal system in 1940 resulted in many difficulties in the treatment process. A more detailed description of the plant facilities is given elsewhere in this issue (page 723); in brief, the plant is an 0.8-m.g.d. chemical precipitation plant with separate sludge digestion and pre- and post-chlorination. Digested sludge is dried on glass-covered beds and then carted to a nearby dump.

Some of the plant problems were found by Superintendent C. B. McMenamin to be due to poor settling in the clarifiers, in spite of good floc formation in the flocculators. Waste temperature differences causing the trouble were remedied by additional retention facilities at the factories and scheduling of the discharges. That did not, however, adequately reduce the high B.O.D. Experiments indicated pretreatment to be uneconomical and anaerobic studies produced no solution.

Municipality and industry then combined forces by building, at the municipal treatment plant, a pilot-scale secondary plant comprising two 15-ft. diameter trickling filters and two cone-bottom steel settling tanks. The flexibility of the plant permits of many valuable test combinations, as the filters can be operated in parallel or in series with various loading combinations. In this way, the industry has the benefit of competent operation of its pilot plant, yet does not have the added expense of an entirely separate plant. The municipality also benefits by having the pilot plant under its

own supervision without excessive additional cost, as it is obtaining extremely valuable design data for its projected secondary treatment additions.

Algae Rarebit

Scientists concerned with methods of augmenting the world's food supply have turned to algae as a possible source of proteins and fats for human consumption. Along this line, Dr. Paul M. Cook, chemical engineer of the Stanford (Calif.) Research Institute, has been attempting to develop a practical continuous process for large-scale culture of algae.

Also, in a series of articles in the British Sunday press, Professor J. B. S. Haldane suggests mass scientific production of selectively-bred green algae of nutritious and tasty varieties. His suggested food factory would introduce the seed algae into a slowly moving stream of water flowing under glass (preferably in some country enjoying plenty of sun) in contact with carbon dioxide enriched air, and addition of sterilized sewage to the stream every few yards as a source of foodstuff. Allowing for time and the amount of sunlight, green algae are expected to be produced in huge quantities that will be extracted from the slowly moving stream, cooked, and canned. The product is described as a "greenish, cheesy kind of food."

Well, we suppose almost anything would be a welcome addition to the "austerity diet" Britons have faced in the past few years!

Cleaning Filter Media Mechanically

Mechanical cleaning of the top layer of ponding trickling filter media can be readily accomplished by using a powered hand cultivator of the rotary hoe type. The method is briefly described in the March, 1952, issue of *The Water and Sanitary Engineer* (British), page 520.

Essentially, the cultivator turns over and loosens a 9-in. depth of the media in a 20-in. wide swath, eliminating the hand labor of forking the bed. According to the report the method has been found to be economically feasible on all but the smallest plants, despite the need for an extra man to push the distributor arm around ahead of the machine. The implication also is given that the rotary hoe can be detached from the tractor element and replaced with other attachments to aid in grounds maintenance.

Radiation Watchdog

A new radiation "watchdog" which sounds an alarm when dangerous atomic radiations become harmful to human tissue will soon be on the job in many American cities, according to *News Digest*, published by General Electric Co.

Called an "area health monitor," the new General Electric device will be installed in atomic energy plants, waterworks, laboratories, hospitals, and other areas requiring records of beta, gamma, or x-ray radiation. Its main function is not to measure intensity of radiation at the source, but to indicate when an area has become sufficiently contaminated to be dangerous to human beings. According to G–E engineers the new health monitor is designed to measure and record what is known as the "ionizing potential" of gamma rays within an area, the important factor in determining the effect radiation will have on human tissue.

Diplomatic Gag

When a recent news wire story gave a New York City sewage treatment worker's duties as "receiving foreign diplomatic envoys and dignitaries, setting up appointments for such per-

sons, and arranging press appointments and releases," a storm of jealous protest was aroused across the country. The justifiable "howls" came from fellow sewage treatment workers, rather than from outraged taxpayers. All, it seems, wanted to know how they too could entertain visiting dignitaries.

None seemed to express the professional reaction, however, as well as one from another New York City employee who wrote the *New York Daily Mirror*, the paper that carried the original story, as follows:

I work for the Dept. of Public Works as a senior sewage treatment worker, so I believe I am qualified to comment on your article.

I am in charge of a sewage treatment plant under the supervision of a senior stationary engineer, and we have four sewage treatment workers here. Now there is quite a bit of confusion.

We would like to know—who are the diplomats we are to receive today? To whom do we send the food and liquor bills?

I told my men not to worry; all they have to do is to receive any of these diplomats at any of our sewage treatment plants—especially when we are cleaning out a pump—and I will personally guarantee the diplomatic situation will be finished in short order.

I would like it to be known that the only diplomats we are interested in are the Communist diplomats. They could stand some of our treatment.

However, I, too, am taking my share of the ribbing from friends and my wife. Now, when I leave home in the morning, she asks:

"Who will you be receiving today? How many women diplomats will be there? Why didn't you tell me about this before."

Though I change my clothes before I leave the plant at night, they still retain a slight sewage smell. My wife, of course, says: "Are you sure you have been receiving diplomats?"

I am getting ready to blow my top. So I hope you will print something to clean up this mess, which is worse than our sewage.

It turned out, however, that it was all just a "diplomatic gag," as the job classification questionnaire under discussion was returned by an ordinary down-in-the-earth sewage worker working off some of his frustrations!

Petro-Chemical Plant desires young Chemical Engineer interested in development program of water treatment and industrial waste disposal including boiler plant, cooling water, biological digestion pilot plants for effluent. Salary commensurate with background. Send outline of training, education, and personal data to Personnel Superintendent, Celanese Corporation of America, Box 148, Bishop, Texas.

Reviews and Abstracts*

Proceedings of the Sixth Industrial Waste Conference. *Eng. Bull.*, **35**, No. 6 (Extension Series No. 76), Purdue Univ. (Oct., 1951).

Oil-Water Separation. By R. N. Giles. Pp. 1–9.

The separator units and their operation over an 18-month period are discussed in This Journal, **23**, 3, 281 (Mar., 1951). This later paper covers two years of operation and gives additional data and graphs.

Daily analyses charts of oil in the effluent show about 65 p.p.m. in December, 1949, and about 45 p.p.m. in July, 1950. The range of oil recovery over a 2-year period was 93.1 to 98.4 per cent, with an average of 96.7 per cent. Oil losses from within the refinery were reduced by 80 per cent during the 2-year period. Factors affecting good recovery are discussed and the author concludes that "complex mixtures of oil, emulsions, and settleable solids retard gravity separation" and that "a gravity-type separator . . . should be regarded as a primary rather than a final treatment." W. Hasfurther

Collection and Treatment of Acid Runoff from Coal Gob-Pile-Storage Areas. By Carl D. Gross and Carl Lee. Pp. 10–21.

Fish kills following a local intense rate of precipitation over the Kincaid, Ill., area during a period of low stream stage were found to be due to the presence of large quantities of acid from gob-pile runoff and leachings. Samples collected after a 4-in. rainfall showed free and total acid concentrations of 4,000 and 19,000 p.p.m., respectively, pH about 2.3, total suspended solids as high as 15,000 p.p.m., and volatile suspended solids of 3,000 p.p.m. Abatement of objectionable acidification of the receiving stream could be accomplished by (a) sealing the surface of the gob-piles to exclude oxygen and prevent the formation of ferrous sulfate, (b) impounding the acid wastes and releasing them only during and in proportion to higher discharge rates of the outlet stream, and (c) a combination of controlled waste discharges and chemical neutralization of acids. Limited use has been made of surface and intra-surface applications of tar, clay, bentonite, and other compounds, for the purpose of excluding air and rainfall from coal mine waste deposits, but the economics of these methods are not well known. The Peabody Coal Co. decided to develop gravity storage of acid wastes so that rates of release could be controlled, and to make provision for the addition of primary and neutralization treatment facilities should these become necessary.

The Use of Vacuum Filtration in Pickle Liquor Disposal. By Edgar F. Guillot. Pp. 22–29.

The Marblehead Lime Co. pilot plant at Chicago, Ill., is described and the results obtained in neutralizing waste pickle liquor are given. In the Marblehead studies comparative filtration rate runs using quicklime slurry and dry quicklime showed that dry lime was superior to lime slurry neutralization, but that the reaction time of the lime slurry was shorter and it was easier to handle, which more than balanced the difference in filtration rate. With dolomitic lime, the reaction time was nearly twice as long as when using hydrated lime slurry, as compared with a quicklime slurry. Dolomitic limes, when easily obtainable, are preferable to high-calcium limes. However, high-calcium lime gave uniformly higher filtration rates (at times 30 per cent higher) with the added advantage of immediate reaction. When dolomitic lime

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 325 Illinois Bldg., Champaign, Ill.

is used the filtrate from this sludge contains a large quantity of dissolved magnesium sulfate. Because the filtrate contains little soluble iron, the filtrate was used for all or part of the lime slaking liquid. Up to 50 to 75 per cent of the lime slaking liquor could be obtained from this source. The remainder of the filtrate is acceptable for diluting fresh batches of pickle liquor. It is stated that no liquid effluent need be dumped into a stream from a lime neutralization plant. The use of filtrate also reduced by 30 per cent the volume of liquid required to slake the lime and still obtain a pumpable slurry. In conclusion it is reported that regardless of the type of lime used for neutralization, results at the Marblehead Lime pilot plant showed that string discharge rotary vacuum filtration is a practical method for disposing of neutralized waste pickle liquor. The application of vacuum filtration to the treatment of tannery wastes, wool scouring liquors, fruit canning wastes, and de-inking wastes is also noted. CONRAD P. STRAUB

Treatment of Powder Plant Wastes. BY BRUCE W. DICKERSON. Pp. 30–42.

This article deals only with the soluble organic wastes produced from operations in cutting, grading, curing, solvent extraction, and alcohol recovery. The waste products are all soluble, high in B.O.D., and, in general, very low in suspended solids. Some are acid and require neutralization before treatment, as their pH is below 4. Their volume is low, averaging about 200,000 g.p.d. for the average plant.

From preliminary studies it was inferred that biological oxidation would be the most satisfactory method of approach.

The wastes were divided into two groups: (1) those from cutting, still house, and auxilary nitration operations, and (2) those from the curing and solvent operations.

Trickling filters were selected as the form of biological treatment. They were of the low-rate, shallow, two-stage variety, accompanied by primary and secondary sedimentation tanks and equipped with pumps for recirculation.

Continuous seeding at the rate of 10 per cent of the waste inflow was maintained from a sanitary septic tank outflow.

Over-all efficiencies of 95 to 99 per cent B.O.D. removal were observed.

GEORGE T. BRYANT

Statutory Developments in the Field of Water Pollution Control. BY CHARLES M. HENDERSON. Pp. 43–50.

In a general way, there are presented the conclusions of a study by the Division of Water Pollution Control, U. S. Public Health Service, and the Office of the General Counsel, Federal Security Agency, on pollution control laws in the various states. The common law and its limitations are discussed. The principal drawback to dependence on the common law is that final decisions must rest with the courts, which can engage in only limited advance planning.

Proper uses of natural resources require planning by governmental agencies and statutes by legislative bodies. The earliest statutes took the form of prohibitions of certain types of polluting discharges. The next important class of statutes was designed for the protection of health. In this area, regulation progressed from prohibitive measures to the vesting of administrative discretion in a technically competent agency.

A great number of miscellaneous statutes, directed in some instances toward the prevention of pollution for the protection of specific stream uses and in other instances toward the exempting of certain industries, resulted in confusing administrative responsibility in many of the states. This led to what is termed "the modern trend," in which all state agencies interested in water pollution are merged into one over-all policy board responsible for promulgating a single set of rules and orders to control the subject from the state administrative level. At present some 30 states have adopted comprehensive legislation of this type.

The over-all agency is charged with controlling pollution so as to permit waters to be put to the best possible use. Its principal tools are generally: (1) limitation of new pollution through requirement of permits for new or increased waste discharges and (2) adequate enforcement powers to clean up existing situations.

Although most of the statutes enacted in the last decade conform to these principles, they vary widely on particular points from state to state. Model legislation for pollution control has been incorporated in a "Suggested State Water Pollution Control Act," which was developed by the Public Health Service and is

sponsored by the Council of State Governments.

In recent years there has been recognition that the pollution problem goes beyond state lines. This has led to the development of several basin-wide compacts for interstate cooperation in pollution control. D. A. OKUN

Development of the Magnesia-Base Pulping Process. BY L. S. WILCOXSON. Pp. 51–56.

It is estimated that 17,000 tons of pulp are produced daily by the sulfite process in the U. S. and Canada from about 36,000 tons of wood chips per day, resulting in the discharge of about 19,000 tons per day of organic solids, 1,600 tons of CaO, and 1,500 tons of S, for a total liquid discharge of about 46 m.g.d. If all the fuel energy in the organic solids could be converted into useful form it would develop over 155,000,000 lb. of steam per day, or 9,100 lb. of steam per ton of pulp produced, and generate 427 kw.-hr. per ton of pulp. Pilot plant studies indicated the feasibility of using the magnesia base in a cyclic process to replace the calcium-base process. In September, 1948, operation of a magnesium-base pulping plant was started at Longview, Wash., at the Weyerhaeuser Co. plant. The process comprises eight principal operations as follows: (1) preparation of magnesia-base cooking acid from re-cycled chemicals (item 7 and item 8); (2) digestion of wood chips by magnesia-base acid; (3) separation of pulp and reclamation of spent liquor from the cooking process; (4) neutralization of the residual liquor, using recovered magnesia (item 7); (5) concentration of the neutralized residual liquor; (6) burning the concentrated residual liquor; (7) recovery of magnesia as inorganic ash from the combustion process; (8) recovery of sulfur from gaseous products of combustion; and (9) preparation of cooking acid as in item 1. The Longview mill has been operating successfully for two years and has demonstrated the commercial practicability of the system. It also indicates a substantial attainment of the economic values anticipated. The author concludes that the use of the magnesia-base process results in the virtual elimination of the stream pollution problem, and provides effective conservation of chemical values.

CONRAD P. STRAUB

Some Legal Aspects of Industrial Waste Problems. BY JOHN H. MURDOCH, JR. Pp. 57–63.

Legal principles which apply to industrial wastes are explained by means of hypothetical examples: a conglomeration of industries, by the discharge of their wastes, has destroyed a public water supply, closed a stream for recreational use, and injured riparian owners; similar industries plan to create similar conditions on a presently clean stream; a third group which may be competitive with the others, owns an entire valley so situated that the wastes can harm no one.

The author concludes that the common law offers no prospect of relief for the people of these valleys. He recommends legislation under the police powers of the state and refers to the Suggested State Water Pollution Control Act as a promising draft for such legislation. Comments on this draft are offered. D. A. OKUN

The Ozonation of Cyanide Wastes. BY RICHARD G. TYLER, WILLIAM MASKE, WILLARD MATTHEWS, AND M. J. WESTIN. Pp. 64–69.

This paper was published in THIS JOURNAL, **23**, 9, 1150 (Sept., 1951).

Disposal of Liquid Wastes by the Irrigation Method at Vegetable Canning Plants in Minnesota, 1948–1950. BY J. A. DRAKE AND F. K. BIERI. Pp. 70–79.

Three plants using spray irrigation, two using ridge and furrow irrigation, and one using both, are described. In spray irrigation, wastes are pumped through portable piping and nozzle systems moved over cultivated fields in a planned cycle. In the ridge and furrow system, distribution is made onto fields plowed in ridges.

Both types were found satisfactory, and in the ridge and furrow method as high as 2.25 in. of waste per acre per day were applied. In two cases where the system was used to supplement lagoons, although no odors were noticed during spraying of fresh wastes, objectionable odors were released from lagooned wastes.

Irrigation has the benefit of eliminating odors, reducing the cost (except where long pumping lines are needed to reach the field), and leaving the ground available for future use. There is, however, a potential danger of foreign matter from

wastes accumulating on plants at the spray field and providing harborage for fungi, roots of growing crops rotting from excessive wetting, and plant diseases being spread from raw products to crops being irrigated. WM. A. HASFURTHER

High-Rate Trickling Filter Pilot Plant Studies. BY NELSON ROBERTS AND J. B. HARDWICK. Pp. 80–87.

By-product recovery units have reduced the pollution load from distillery plants by 95 per cent. This paper is concerned with studies made on the residual waste load in attempts by the Joseph E. Seagram & Sons, Inc. at their Lawrenceburg plant to reduce the distillery pollution beyond that possible due to recovery alone. Plants operating complete by-products recovery units have been able to reduce the pollution load in terms of population equivalent from 60 to 70 per bushel of grain mashed and distilled to 2 to 3. Study indicated that approximately 53 per cent of the residual pollution B.O.D. came from process flows and 47 per cent from floor washings, etc. Of the process B.O.D., approximately 77 per cent originated in the waste condensate from the quadruple-effect evaporators, which concentrate the thin stillage prior to final drying. The waste condensate is a clear liquor with a pH of approximately 3.8 and an average B.O.D. of 685 p.p.m., which comes from volatile organic compounds driven off the stillage in the evaporator. It contains less than 1 p.p.m. nitrogen, no phosphorus, and 1.0 to 1.5 p.p.m. copper. A study of the literature indicated that wastes high in organic content could be treated on high-rate trickling filters, and that in distillery applications the filters were designed for loadings of 0.75 lb. of B.O.D. per cubic yard of filter bed per day. Through a study of the operational factors involved, the authors hoped to operate the units at higher rates than noted above. A pilot plant including a 24-in. diameter primary clarifier with a vertical central baffle extending to within 6 in. of the tank bottom, an 8-ft. filter 24 in. in diameter containing 2- to 3-in. stone packing and provided with sampling ports at 2-ft. intervals, and a final clarifier, was built. Nutritional supplement in the form of either ammonium hydroxide solution or an ammonium hydroxide-ammonium phosphate mixture is added to the primary clarifier. Some experimental results are reported; the best indicating that with a feed of 1.1 lb. B.O.D. per day per cu. yd., a dosing rate of 30 m.g.a.d., and a recycle ratio of 11:1, the over-all B.O.D. removal was 77 per cent. The authors report that more work will be required in which the following factors will be evaluated: effect of dosing rates, recycle ratio, filter feed rate, temperature, forced air circulation, and optimum filter depth.

Biological Observations and Toxicity Bioassays in the Control of Industrial Waste Disposal. BY PETER DOUDOROFF. Pp. 88–104.

Biological studies of industrial pollution of water should be directed primarily toward reliable estimation and understanding of the effects of pollutants on aquatic resources of economic and recreational import. Industrial waste disposal should be controlled so as to avoid any direct or indirect damage to these resources. These objectives often cannot be achieved through physical and chemical examination of wastes and receiving waters, and through studies of those aquatic organisms which are of no immediate value to man, and which are considered only as indicators of stream conditions. When it is not necessary, influential estimation of pollutional damage to fish life is discouraging and a direct approach to the evaluation of fish habitats and their productivity, and of the toxicity of wastes, is recommended. Comparative studies of fish populations and fishing success in comparable polluted and unpolluted waters are most pertinent. Studies of the bottom fauna (benthos) and of plankton also can be very instructive, but the relative importance of these various organisms as food for desirable fish species should be a major consideration in the conduct of such studies. Toxicity bio-assays of industrial wastes help to explain and to predict effects of industrial pollution and of remedial measures.

Standards for Treated Industrial Wastes. BY F. P. MILLIGAN. Pp. 105–121.

The purpose behind the development of water quality standards (dilution, effluent quality, or stream quality standards) is to provide a tool for use in the protection of

public waters. Treatment to abate pollution, one of the most important measures for stream protection, is cheaper at the source than the sum of the costs at the points of use. Treatment at the source likewise places the cost on the originator of the damage. Effluent standards are useful criteria, particularly in the early stages of stream clearance programs in heavily industrialized areas, if they are properly determined and are applied with due consideration of the categories of the stream involved. In the later stages of restoration, stream quality standards have a definite place. Dilution standards are not adequate, as they are only approximate and cannot be applied to all stream conditions. Following a review of effluent standards established by other state and regional groups, the author discusses the effluent standards used in Pennsylvania. Industrial establishments are required to provide treatment of their waste waters equivalent to that for sewage, based on careful study and investigation. Primary treatment of sewage is defined as the removal of practically all settleable solids and at least 35 per cent of the B.O.D., effective disinfection of pathogenic organisms, satisfactory disposal of sludge, and a final effluent suitable for discharge into the public waters. In addition, oils, greases, acids, alkalies, toxic, putrescible, taste- and odor-producing substances, and other substances inimical to the public interest in the receiving stream must be removed. Complete treatment of sewage is similarly defined, except that removal of practically all of the suspended solids and at least 85 per cent of the B.O.D. load is required, plus effective disinfection. Intermediate treatment is defined in accordance with the need in each instance. Through the cooperation of industry committees with the state authorities, standards have been established for the wastes from milk processing plants; from oil, natural gas, and other wells; acid pickling liquors and metallurgical plants; and all wastes from pulp and paper mills in Pennsylvania. Similar standards are currently under development for the tannery and textile industries; eventually standards will be developed for all waste-producing industries in the state.

Processing Citrus Cannery Waste. By Dan B. Vincent. Pp. 122–129.

Citrus cannery waste, a by-product of the processing of grapefruit, oranges, and lemons, is a mixture of the peel, rag, and seed of the fruit, surplus juice, water from washing operations, and blemished fruits, and is a slick, slimy, non-uniform mass containing about 83 per cent moisture. During the Florida cannery season, which begins in late October or early November and continues through May or June, it is estimated that 2,400 m.g. of waste are produced in processing about 59 per cent of the entire fruit crop of the state. The problem of handling proportional amounts of waste also exists in California, Texas, and Arizona. In Florida in 1924–25, it was found that dried grapefruit waste could be used as a dairy feed, and in 1926–27 similar findings were made with orange wastes in California. Since then much study has been given to the recovery of this material and processing it for use as an animal feed. These developments and their attendant difficulties are reviewed by the author. The studies culminated in the development of the crusher roll method in Florida and the "sausage" method in California, and were continued until 1937 when two feasible methods for the chemical treatment of the wastes were developed. In the Neal process, the waste was ground in conventional hammer mills, hydrated lime was added, the mass was aged for several hours, then pressed, dried, and bagged. In the Vincent process, the waste was coated with hydrated lime, shredded, and passed to a conveyor permitting weak gel formation, where residual acid caused collapse of the gel. The formerly slimy, colloidal mass changed to a whitish spongy material and free watery liquids, which could be removed easily. Press liquors from both processes result in a straw-colored liquid containing 8 to 15 per cent dissolved solids, of which about 50 per cent are sugars. This is further processed and about 1 per cent fine, suspended, slimy, minute, gelatinous solids remain, which are difficult to remove without pretreatment. If disposed on land, nuisance conditions would arise; if disposed in streams further nuisances due to oxygen depletion would result. Experiments to make simple sugar syrup from these press liquors proved practical and a pilot plant was built. The process employed involved clarifying the liquors of suspended solids

by heat treatment at controlled pH, decanting, passing the liquors through cation and anion exchangers, filtration, and concentration of the clarified syrup. Because of the cost of equipment no commercial installation has been built. During recent years, these press liquors have been concentrated to feed molasses, but being in liquid form it is difficult to market. A new method, which partially overcomes this objection, has been developed and produces a dried feed containing 75 per cent molasses solids.

The Use of Industrial Waste in Poultry Feeding. By C. W. Carrick. Pp. 130–134.

Numerous examples are given of the growth-promoting substances found in various industrial waste by-products and desirable for use as poultry feed supplements. Any product that can supply desired nutritional values at a lower cost will likely be acceptable, provided it is uniform in composition, readily digestible, and free from harmful effects upon the animal and the market products (eggs, milk, etc.). Some of the substances found in waste products are as follows:

Waste Material	Nutritional Product
Fermentation wastes:	
Condensed or dried solubles	B-complex vitamins (riboflavin, pantothenic acid, niacin, and choline)
Specially fermented stillage	Riboflavin
Antibiotic wastes (aureomycin, bacitracin, penicillin, streptomycin, terramycin, etc., manufacture)	Vitamin B_{12} and antibiotic activity
Fish Products:	
Press water, condensed fish solubles	Vitamin B_{12}, other B-complexes, protein
Whey wastes:	
Whey solubles	Riboflavin and pantothenic acid
Beet sugar wastes	Betaine, which is effective for replacing choline
Dried vegetable waste	Carotene (precursor of vitamin A) and other vitamins

Conrad P. Straub

Treatment of Chromium Wastes by Ion Exchange. By Richard G. Tyler, William Maske, and Milton J. Westin. Pp. 135–140.

This paper was published in This Journal, **23**, 8, 1032 (Aug., 1951).

Safe Handling of Hexane in Soybean Processing. By R. E. Greenfield. Pp. 141–147.

The precautions necessary to insure safety from the hexane necessarily lost in soybean processing are dealt with. The loss may be appreciable, amounting to several tank cars a week in the larger plants. The major emphasis is on proper ventilation and remembering that, because hexane vapor is a heavy gas, precautions must be taken to prevent it from accumulating in pits and sewers.

George T. Bryant

Factors Affecting the Lagooning of White Water. By H. R. Amberg. Pp. 148–157.

Tests were made on settled white waters from paperboard mills having average B.O.D.'s of about 250 p.p.m. Lucite columns and beakers of 6-in. diameter were used as lagoons.

By adding nutrients it was found that detention time could be cut in half. The major factor was the surface-to-depth ratio; at an 8-in. depth a 70 per cent B.O.D. reduction was obtained in 6 days, whereas at 4- and 6-ft. depths equal reduction was not reached in 30 days. Reduction in B.O.D. increased rapidly to an optimum point between 30° and 40° C., after which point it increased very little or decreased. Inoculation with seed showed some improvement, a seed-to-feed ratio of 0.67 being recommended. Intermittent aeration was tried using 5-min. periods at various intervals and a 4-ft. water depth. B.O.D. reduction was 70 per cent in 5.5 days at the 30-min. interval, compared to a 32-day period required for like reduction without aeration. Discussion of this work in conjunction with reports of other workers shows these results reliable for determining optimum lagooning conditions.

Findings from a Cooperative Study of Phenol Waste Treatment. By E. J. Cleary and J. E. Kinney. Pp. 158–170.

This is a report of the thinking leading up to, and of, experiments and pilot plant studies at an Armco Steel Corp. coke plant, on chemical oxidation of phenols. Results of pretreatment by acidification, chemical coagulation, and permanganate, none of which were considered successful, are also reported.

It was found that complete destruction of phenols could be accomplished by oxidation with the three agents tried: chlorine, ozone, and chlorine dioxide. Chlorine was effective in detention times ranging from 10 min. to 1 hr. over a wide pH range, but where ammonia was present it first had to be oxidized, and, if the reaction was not complete, chlorophenolic tastes resulted in the treated water. Ozone reacted rapidly and best at a high pH, the reaction was not interfered with by ammonia, and treatment could be carried to any point without the formation of more toxic or taste-producing compounds. Chlorine dioxide treatment needed no pH adjustment, there was no interference from ammonia, and undertreatment did not cause chlorophenolic tastes. A discussion is also included on methods used for determining phenol concentration, including the Gibbs and DAAP tests. A full report in bulletin form has more recently been published by the Ohio River Valley Water Sanitation Commission, Cincinnati, Ohio.

New Design for an Activated Sludge Plant to Treat Milk Wastes. By Paul M. Thayer. Pp. 171–175.

Descriptions and operation data are given for two small activated sludge plants for treating dairy wastes. One plant consists of two aeration tanks followed by settling, and the other has a holding tank, one aeration tank and a settling unit. All sludge is returned to the aeration tanks by an air lift.

Tests covering about three weeks at each plant gave the following data, respectively: flow, 4,400 and 7,200 g.p.d.; aeration time, 39.4 and 41.2 hr.; B.O.D. of raw waste, 567 and 926 p.p.m.; B.O.D. of final effluent, 19 and 31 p.p.m.; and air supplied, 5,880 and 3,570 cu. ft. per pound of B.O.D. in raw wastes. The writer lists 10 items, such as air required, holding tank capacity, pump capacities, etc., as a basis of design for this type of plant.

W. Hasfurther

Poultry Dressing Waste. By Perry E. Miller. Pp. 176–180.

A plant was designed to dress about 5,000 chickens per day (20,000 lb. live weight). The liquid waste from poultry dressing contains varying amounts of blood, feathers, fleshings, washings from evisceration, digested and undigested food, manure, and dirt. All wastes go to floor drains, through sewers to two parallel 225-gal. screen pits provided with ¼-in. mesh vertical screens, to a 14,430-gal. septic tank, and to a 300,000-gal. lagoon draining by seepage into an underlying gravel stratum. Ammonium nitrate has been used to control odors. About 20 lb. per day are used during the summer and about 5 lb. per day during the winter. A single day's analysis of a 9-hr. composite sample is reported and shows a 5-day B.O.D. of 385 p.p.m., suspended solids 248 p.p.m., volatile suspended solids 232 p.p.m., total solids 993 p.p.m., volatile total solids 477 p.p.m., pH 7.3, and average waste flow 49 g.p.m. Screening and passage through the septic tank accounted for a 62.8 per cent reduction in B.O.D. and lagooning reduced the B.O.D. to 27 p.p.m. for an over-all removal of 92.9 per cent. Loading factors reported for each 1,000 lb. of live weight processed were B.O.D. 5.6 lb. for a population equivalent of 33, suspended solids 3.6 lb. for a population equivalent of 18, and a waste volume of 1,760 gal.

Removal of Cations from Chromic Acid Solutions. By D. M. Stromquist and A. C. Reents. Pp. 181–189.

The problem of cation removal from chromic acid solutions is considered in order that chromic acid bath life may be prolonged and that costly chrome disposal treatment may be avoided. Chromic acid baths are generally contaminated by metal ions, such as iron, copper, zinc, and other metals. Chromic acid plating solutions generally contain 250 to 400 g. of chromic acid per liter of water, and are adjusted or dumped when the metallic contaminant concentration reaches approximately 10 to 15 g. per liter, or when faulty plating occurs. Styrene divinyl benzene type cation exchangers on the hydrogen cycle were stable and could be used with diluted chromic acid solutions containing up to 150 to 200 g. CrO_3 per liter. Minimum oxidation of the resin

occurred at concentrations of 70 to 100 g. of CrO_3 per liter and the most complete exchange was also obtained in this concentration range. Flow rates through the exchange columns were held at 3 g.p.m. per square foot. Trivalent chromium could also be removed by this procedure. In treating about 37 gal. of chromic acid solution containing 2.95 g. CrO_3 per liter, an over-all removal of 60 per cent of the trivalent chromium was obtained. A recovery system suggested for contaminated baths includes CrO_3 dilution and passage of the liquid through a hydrogen exchanger, followed by evaporation of the filtrate to the desired working concentration. Anodizing solutions containing 75 to 150 g. CrO_3 per liter which became contaminated by aluminum could be treated by cation exchange for aluminum without prior dilution. The maximum permissible concentration of aluminum in the anodizing baths is 12 g. (as Al_2O_3) per liter. The cation resin used was ILLCO-C-231 on the hydrogen cycle. The aluminum concentration during the run was held to less than 0.2 g. per liter (as Al_2O_3), providing the capacity of the exchange material did not exceed 25 gal. per cu. ft. A waste recovery plant similar to the one above is suggested. Some cost data are included. The author concludes that purification of chromic acid solutions by cation exchange presents a logical answer to the platers' problems, for the waste disposal problem is practically eliminated and the process also assists in the conservation of a very critical material.

Lake Pollution from Entering Streams. By C. C. DeWitt and J. F. White. Pp. 190–204.

A study was made of the discharge of pretreated sewage and industrial waste effluent into Fremont Lake. The sewage from Fremont, Mich., and cannery wastes from the Gerber Products Co. are treated in the municipal sewage treatment plant, which includes facilities for sedimentation, high-rate biological filtration, and partial chlorination before discharge into Darling Creek, a feeder stream to Fremont Lake. Chemical (dissolved oxygen and B.O.D.) and bacteriological data included show the distribution of the wastes in Fremont Lake. The study was inaugurated in May, 1950, and was continued, weather permitting, through the fall and winter of 1950. Data presented indicate that during the period May 19, through October, 1950, the creek mouth showed low D.O. values, sometimes even zero values. During the period of the study, the highest 5-day B.O.D. value reported was 670 p.p.m., again in the creek mouth; the highest value reported in the lake was greater than 160 p.p.m. On the basis of the bacteriological data given, the authors feel that the lake is in poor condition for bathing, at least in the area investigated. A table is included showing the variation in B.O.D. and D.O. throughout the course of the day on two sampling days. These data are quite interesting, although it is unfortunate that they were taken in the winter months. Conrad P. Straub

Sanitary Engineering and Waste Disposal Problems in the Atomic Energy Industry. By Arthur E. Gorman. Pp. 211–220.

The role of the sanitary engineer in the atomic energy industry is presented, together with the problems with which he is faced. Also summarized is the research being conducted at various AEC installations and universities in an attempt to alleviate the problem of disposal.

One interesting point brought out is that, in the case of wastes containing long half-life isotopes, even though changes of state are brought about, there still remains a hazardous waste to dispose of.

George T. Bryant

The Application of Oxidation-Reduction Potential to Biological Waste Treatment Process Control. By W. W. Eckenfelder, Jr., and John W. Hood. Pp. 221–238.

The characteristics of oxidation-reduction potential (O-RP) measurements are defined under a variety of conditions and test materials. The effect of pH on O-RP is noted and, in general, it may be stated that the O-RP in millivolts falls with increases in pH. The techniques of making measurements are fully described and conclusions to be drawn from the O-RP measurements in investigating the effects of aeration on tomato canning process wastes, biological activity in the activated sludge process, anaerobic decomposition, trickling filter operation, and effect of nitrate treatment on odor production from synthesized tomato wastes. The characteristics of wastes and their effects on

plant loadings are qualitatively indicated, as shown by some reported values for a plant receiving domestic sewage, textile, dairy, laundry, and cannery wastes. The authors indicate that further studies are under investigation which will define more closely the effects of specific processes on O-RP measurements. CONRAD P. STRAUB

The Administration of Stream Pollution Prevention in Some States. BY HAROLD E. BABBITT. Pp. 239–252.

The author reports his conclusions after visits to stream pollution control authorities in 26 states. Comments are offered and state laws are abstracted and quoted to emphasize certain administrative trends.

Administration of stream pollution prevention varies from state to state and in general is in a condition of flux. Variations in control in Massachusetts, California, Maryland, Connecticut, Virginia, and Illinois are discussed. The standardization of streams, with New York State law as an example, is discussed. Sections of the law are quoted at considerable length.

The role of interstate pollution control authorities is discussed and a list of these is presented.

The author discusses the attitudes toward pollution control that he found in talking with (1) enforcing authorities, (2) polluters, (3) users of the stream, and (4) the general public.

A recent trend in state legislation toward divorcing the control of stream contamination from the control of stream pollution is noted. The removal of pollution control authority from the Board of Health in California to Regional Water Pollution Control Boards is commented upon in some detail, with mention of similar situations in Maryland and Connecticut.

In some states, typified by South Carolina, a water pollution control authority exists within the state health department.

In summary, of the 26 states visited, complete jurisdiction over all stream pollution is assigned to State Health Departments in 20 states, whereas in the 6 other states these departments have lost control of pollution not directly affecting the health of the people. D. A. OKUN

Preventing the Discharge of Silt from Collieries. BY C. L. SIEBERT, JR. Pp. 253–271.

The discussion is primarily concerned with preventing the discharge of silt produced in the preparation of anthracite coal, because in Pennsylvania the silt problem in the anthracite region has been more extensive and serious than in the bituminous region, and because the principal effort has been directed to anthracite silt control. The various methods in use for the hydraulic separation of coal are described. The most recent innovation in the preparation of fine coal is the use of the froth flotation process, in which coal particles are treated with oil and a frothing agent. Even with recirculation, approximately 1,000 gal. of water are required per ton of marketable anthracite, as compared with 50 gal. per ton of bituminous coal. There has been a steady decrease in the discharge of fine coal solids to the streams, which in 1920 was estimated at 1,800,000 tons to the Schuylkill Basin and in 1942 was estimated at 660,000 tons. Pennsylvania's basic pollution control act, passed in 1937, specifically exempted acid mine drainage and silt from coal mines until practical means for their treatment were available. On the basis of experimental studies by the Pennsylvania Department of Health, 3-hr. nominal detention in settling basins and about 3 ft. per hr. upward velocity in mechanically cleaned clarifier units were accepted as tentative design criteria. In 1945 the legislature amended the Act and removed the exemption of silt from coal mines. Several methods have been suggested for silt removal, the cheapest and simplest being to discharge the silt laden waters into abandoned mine workings. The most widely used method of disposal is the operation of silt basins. A theoretical detention period of 3 hr. will produce an effluent containing well under 1,000 p.p.m. suspended solids. One foot of weir length for each 200 g.p.m. of effluent has proved satisfactory. Scrapers for mechanical removal of silt are used, but at velocities of at least 6 ft. per min. However, the effluent from such tanks requires additional treatment before discharge to surface streams. Circular mechanically-cleaned thickeners have been used, but these have developed in size so that they operate more as true clarifiers than as thickeners. With an upward velocity of not over 3 ft. per hr., effluents under 1,000 p.p.m. have been produced. Of the 183 establishments

now engaged in the preparation of anthracite coal by wet processes, 159 have completed and placed in operation adequate facilities for the retention of wastes solids, 19 have works under construction, and 5 have as yet taken no appreciable action. In 1946 the daily discharge of silt amounted to about 19,000 tons per day; at present it is less than 2,000 tons per day for the entire anthracite region, as against 28,000 tons per day of material that may be classed as silt being retained by the collieries. In the Schuylkill Basin the reduction has been from 300,000 tons in 1946 to probably less than 4,000 tons for 1950, all of this being fine material which does not impose a bed load upon the stream. The increased use of fine sizes of coal has materially aided the stream clearance program, while at the same time, the stream clearance program has probably helped develop the usage of fine sizes.

Chemical Flocculation of Refinery Waste Water. By R. J. Austin and E. H. Vause. Pp. 272–277.

Results are reported of a pilot plant investigation to study the applicability of commercially available flocculation equipment in treating refinery wastes from the Whiting refinery of the Standard Oil Company (Indiana). Preliminary jar test studies indicated that dolomitic lime was the best chemical tried for maintaining the pH in the desired range, and that ferrous sulfate was the most satisfactory flocculating agent, as it produced a satisfactory effluent over a pH range of 8 to 10. The addition of 25 p.p.m. of ferrous sulfate, 10 p.p.m. activated silica, and approximately 150 p.p.m. of dolomitic lime when operating at a temperature range of 85° to 95° F., and a rise rate through an Accelator of 0.60 g.p.m. per sq. ft., resulted in the following per cent removals (the first value is the initial concentration, the second the final concentration, and the third the per cent reduction): oil content, 60 and 5 p.p.m., 91 per cent; threshold odor number, 20,000 and 1,000, 95 per cent; turbidity, 150 and 10 p.p.m., 93 per cent; suspended solids, 25 and 10 p.p.m., 65 per cent; dissolved solids, 375 and 340 p.p.m., 10 per cent; chemical oxygen consumed, 140 and 60 p.p.m., 57 per cent; and B.O.D., 60 and 30 p.p.m., 50 per cent. Minimum chemical requirements have not been firmly established. It is concluded that chemical flocculation is an effective means of improving the quality of the waste water with respect to those properties associated with oil content and other suspended matter; reductions in oxygen demand characteristics were substantially lower.

State and Federal Cooperative Activities Under the Water Pollution Control Act of 1948. By A. H. Wieters. Pp. 278–284.

Brief mention is made of some of the cooperative state and federal activities under the Water Pollution Control Act of 1948. Included is a discussion of the progress being made in the preparation of the 15 major drainage basin summary reports and in the compilation of data on pollution from municipal and industrial sources, of the activities of the Water Pollution Control Advisory Board and the National Technical Task Committee in Industrial Wastes, of the adoption of state and federal legislation on water pollution control, and of the effect of the present national emergency on water pollution activities. Some statistics of interest indicate that there are over 22,000 significant sources of pollution almost equally divided between municipal and industrial sources (11,800 and 10,400). The pollution load discharged by municipal sources comes from a total sewered population of 92,000,000; some degree of treatment serves a population of 56,000,000. About 6,000 industries produce organic wastes; more than 2500, inorganic wastes; and 600, both types. For more than 2,000 industries data on the kinds of wastes are still needed. Of the industrial sources, 2,600 have some kind of treatment, 3,600 are untreated, and information is lacking on 4,000. Conrad P. Straub

The Formation of Acid Mine Drainage. By Kenneth L. Temple and Arthur R. Colmer. Pp. 285–291.

Two separate findings of research activities, sponsored by the Bituminous Coal Research, Inc., fellowship at West Virginia University, encouraged more intensive study of the biological aspects of acid mine water. Reported in 1948 by Hinkle and Koehler, these may be summarized as follows: (1) That sulfur-oxidizing bacteria are present in acid mine waters and that their role in contributing to the acidity

should be investigated; and (2) that the oxidation of ferrous iron in acid mine water to produce the characteristic red color takes place only under conditions which show that the process is a biological one and not a simple atmospheric oxidation.

Recent studies have substantiated the earlier conclusions that the ferrous to ferric change of iron contents in acid mine drainage, pH probably in the range of 2 to 3, is biological and requires the presence of specific bacteria. Ferrous iron is oxidizable to ferric by air under ordinary conditions, but is stable to atmospheric oxidation in acid solutions in the absence of bacteria. These bacteria represent a new species with the generic classification still in doubt.

The sulfur-oxidizing bacterium discussed in the earlier studies mentioned has been identified. It is *Thiobacillus thiooxidous*, which obtains its nutrient requirements from sulfur and sulfur compounds, and in so doing oxidizes them to sulfate, whereby sulfuric acid is manufactured. The logical assumption is that when these bacteria are found in mine waters they are actively contributing to the acidity.

Recent investigations of mines on two seams have given more specific evidence of the association of bacteria with acid mine waters. It is indicated that major sources of acid water can generally be attributed to readily oxidizable sulfuritic materials in the shales and rider coals of roof strata. Differences in the composition of overlying soil strata and the degree of disturbance of the strata to produce exposure of sulfuritic materials have a definite bearing on quantities of acid water experienced. BRUCE M. MCDILL

Handling of Metal-Bearing Wastes at Erie, Pennsylvania. BY JOHN W. TOWNSEND. Pp. 292–303.

Wastes at the General Electric plant are collected in three separate systems: spent acid, cyanide-bearing water, and metal-bearing water.

Spent acids requiring neutralization are isolated and pumped or hauled to underground tanks for treatment with lime, and also, in cases where metals are to be reduced, with ferrous sulfate or sodium metabisulfate.

Cyanide waters are collected in sumps or tanks at each installation and ejected by means of float-controlled pumps to storage and treatment tanks. Batch treatment is made with lime and chlorine, and after settling, the upper two-thirds of the tank is decanted off over 16 hr. Nearly 200,000 g.p.d. of cyanide waste containing 35 p.p.m. cyanide is treated.

Wastes containing salts of chromium, copper, and aluminum are mixed and treated first with ferrous sulfate or sodium metabisulfate to reduce the chromium. Then, in a Cyclator, they are mixed with sludge from the cyanide tank, treated with lime, and settled. The clarified liquid is then drained to the sewer.

Sludge from the Cyclator is blended with neutralized acids and fly ash is added. After settling overnight the supernatant is decanted off to the metal-bearing waste receiving tank and the sludge is dried on filters and used for fill. Drawings of the various treating systems are shown and methods of regulating flows, treating, and pumping are described.

W. HASFURTHER

Chemical Treating Plant for Refinery Waste Water from White Oils and Petroleum Sulfonates. BY H. SCHINDLER. Pp. 304–312.

A procedure is described for treating waste water containing water-soluble sulfonates originating during the manufacture of white oils by treating petroleum fractions with sulfonic acid. Suitable petroleum fractions are repeatedly treated with fuming sulfuric acid until all colored compounds and hydrocarbons able to react with sulfuric acid have been removed from the oil. Sulfonation products of alkylated aromatics and tarry polymers are formed; the sulfonates remain either dissolved in the oil or separate, together with unused sulfuric acid and polymers in the form of "acid sludge." After removal of the sludge, the acid-treated oil is finished by neutralization with caustic. The acid sludge is converted into H_2SO_4 and coke, and the oil-soluble sulfonates, being valuable by-products, are recovered and carefully purified. Spills, periodic cleaning of equipment, and the purification process for oil-soluble sulfonates account for their presence in the waste water. Waste waters from this source also contain some caustic, dissolved sulfates, and some emulsified oil from the neutralization of acid-treated oils. Approximately 18,000 to 40,000 g.p.d. of this

waste are produced, of which the following composition is representative: oil, 0.5 per cent; NaOH or H_2SO_4, 0.5 per cent; Na_2SO_4, 5.0 per cent; and color, 1,000 to 5,000 p.p.m. Another 180,000 g.p.d. of hot (180° F.) waste containing 0.1 to 0.2 per cent H_2SO_4 is produced in the manufacture of H_2SO_4 from acid sludge. The aim of treating process waste water is to obtain proper pH adjustment, remove the dissolved petroleum sulfonates as indicated by reduction in color, and remove suspended or emulsified oil. This aim could be reached by acidifying the alkaline waste to pH 5, and precipitating the sulfonic acids as water-insoluble calcium salts by adding hydrated lime to a pH of 7.5 to 8.5. The precipitate formed adsorbs most of the oil and the effluent is practically free of oil. To aid precipitation ferrous sulfate was added. The treatment procedure was effective in that a color reduction of 96 per cent was obtained, a reduction in oxygen consumed of 82 per cent, and a reduction in oil content of about 99 per cent. For full-scale treatment combination of the wastes was resorted to and a mixture of 85 per cent acidic water with 15 per cent process waste treated with enough hydrated lime to obtain pH 8.4 gave an effluent of excellent quality. Data included show a reduction of 87.2 per cent in the oxygen consumed and 82.7 per cent in the color. Addition of 212 lb. lime per 10,000 gal. of waste showed further reductions of 94.2 and 98.9 per cent, respectively. A description is given of the process-water collection system and of the treatment plant. The lime sediment is stored in a lagoon, periodically hauled away by a tank truck, and dumped in a sealed, abandoned shaft mine for final disposal. It is reported that the effluent contains about 45 p.p.m. of color for a removal of 98 per cent, that about the same reduction is obtained in oxygen consumed, and that about 7 tons of lime are required per m.g. of waste treated.

CONRAD P. STRAUB

Aeration as a Partial Treatment for Dairy Wastes. BY SAM HOOVER, JANET B. PEPINSKY, LENORE JASEWICZ, AND NANDOR PORGES. Pp. 313–319.

Laboratory experiments have shown that wastes containing up to 1.0 per cent skim milk solids can be treated by aeration and centrifuging with reductions of 50 per cent of the chemical oxygen consumed and 75 per cent of the B.O.D. to be expected.

GEORGE T. BRYANT

Cyanide Disposal after Plating Cycle. BY C. F. HAURI. Pp. 320—323.

The content of this article is essentially covered in a paper by the same author, published in THIS JOURNAL, **23**, 1, 78 (Jan., 1951).

Management's Approach to Waste Disposal and Stream Pollution. BY FRANK M. SHIPMAN. Pp. 324–328.

In presenting a comprehensive approach of industrial management to the problems of liquid wastes disposal and stream pollution the author selects five categories considered to be of major importance; *viz.*, (a) custom, (b) objective of regulatory agencies, (c) education, (d) cooperation, and (e) cost.

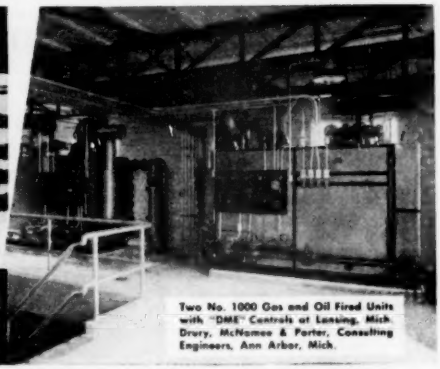
Industrial establishments have been concentrated at points of vantage with reference to raw materials, sources of power, ease and economy of transportation, and availability of personnel; streams have been used for disposal of sewage and industrial wastes resulting from such concentrations and from congregations of masses of people in limited areas. The problem of the future resolves itself into (a) a practical approach to pollution correction by established municipalities and industries and (b) the prohibition of increased industrial activities in overcrowded areas.

Cooperative effort is the essence of the successful approach to pollution abatement and control. Assistance to regulatory agencies by technical men of industry in wastes definition and evaluation is advocated.

Industrial management has a definite responsibility of accounting in terms of a "dollars and cents" yardstick. Consequently, the cost of installations for prevention of stream pollution, as for installations pertinent to any phase of production, must be analyzed from the standpoint of economy.

BRUCE M. MCDILL

[Abstracts of the remaining papers of this meeting will be published in the July issue of THIS JOURNAL.—Ed.]



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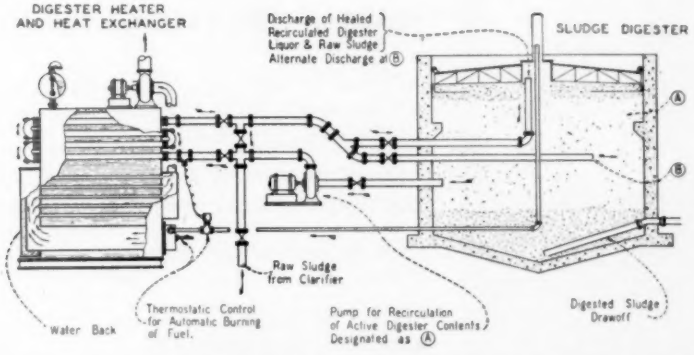
DIGESTER HEATER AND HEAT EXCHANGER
Discharge of Heated Recirculated Digester Liquor & Raw Sludge Alternate Discharge at (B)
SLUDGE DIGESTER
(A)
(B)
Raw Sludge from Clarifier
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Proceedings of Member Associations

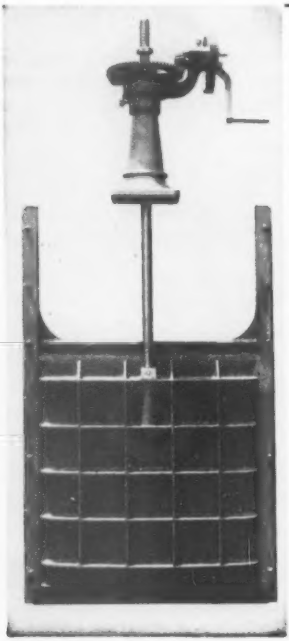
FSIWA MEMBER ASSOCIATION FORMED IN NEBRASKA

The roster of Federation Member Associations, reduced by one in 1951 when the temporarily inactive Argentina group was suspended, was restored to its all-time high total of 37 with the creation of the new Nebraska Sewage and Industrial Wastes Association on April 10, 1952. The organization meeting, held at the Lincoln Hotel, Lincoln, Nebr., was attended by 24 sewage works operators, consulting engineers, and others. Leadership in the move to organize the Association was afforded by R. M. Babcock, Sanitary Engineer, Nebraska State Department of Health, and D. R. Hill, Manager of Utilities, Hastings.

Creation of the new association in Nebraska leaves the states of Mississippi, Nevada, and Utah as the only ones not now included in the territory of the Federation.

The organization meeting was opened by Mr. Babcock and W. H. Wisely, FSIWA Secretary, who outlined the functions and activities that could advantageously be undertaken by the proposed association. A short discussion period was followed by actions providing for organization of the group and for adoption of a constitution and by-laws. Officers elected were: David R. Hill, President; M. S. Fitzsimmons, Vice-President; Paul W. Mousel, Secretary-Treasurer; Scott Wilber, FSIWA Director.

(*Continued on page 242a*)



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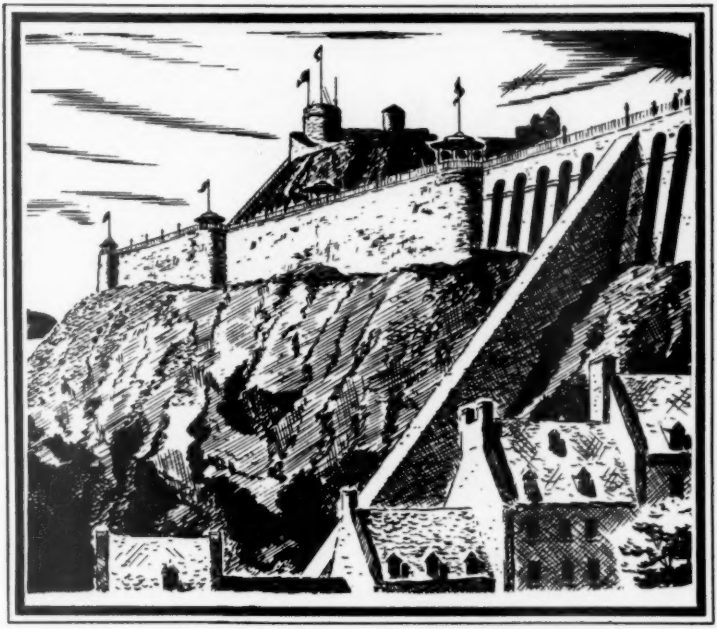

Quebec's famous Citadel, over 330 feet above the St. Lawrence, as it looked 100 years ago

Romantic Quebec has a cast iron gas main in service that was installed over a century ago. Reminiscent of those days are the horse-drawn vehicles for nostalgic tourists. Now, how could the gas engineers have foreseen the advent of trailer-trucks and giant buses and the resultant traffic-shock? . . . That sewers and conduits for utility services would ultimately share the underground at risk of soil disturbances? Yet that gallant old cast iron main has had the necessary shock-strength and beam strength. Effective resistance to corrosion, as well as strength, are *must* factors of long life in pipe to be laid under city streets. This is shown by the fact that cast iron water and gas mains, laid over 100 years ago, are still serving in the streets of more than 30 cities in the United States and Canada.

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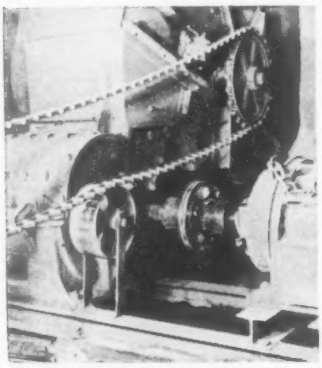
George, AFB, Calif. — Staunton, Va.
Gainesville, Fla. — Burlington, Vt.
Alexandria, Minn. — Cheyenne, Wyo.



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The following charter members were enrolled at the meeting in addition to the above-named officers: R. M. Babcock, E. E. Borden, Loren Brannen, John Cressman, Charles Flick, Harry Flick, J. M. Orrell, W. F. Rapp, Jr., E. L. Thompson, O. F. Barklage, Charles Welton, Frank Travis.

OKLAHOMA WATER, SEWAGE AND INDUSTRIAL WASTES CONFERENCE

The 1951 Annual Meeting of the Oklahoma Water, Sewage and Industrial Wastes Conference was held December 3–7, 1951, at Oklahoma A. & M. College, Stillwater, Okla., in conjunction with the 25th Water, Sewage and Industrial Wastes Short Course. Registration totaled 138.

Lectures, panel discussions, and laboratory sessions comprised the bulk of the technical program. Topics covered in the sewage works and industrial wastes courses ranged through the wide variation in interests of the group. Specific papers of interest included:

"Considerations in Conditioning Waters for Subsurface Injection," by J. W. Watkins, Petroleum Experiment Station, U. S. Bureau of Mines, Bartlesville.

"What the Refineries are Doing to Prevent Stream Pollution," by L. W. Evatt, Oklahoma Planning and Resources Board.

"Why Save Our Streams," by W. H. Wisely, executive secretary, FSIWA.

At the Annual Business Meeting, the following officers were elected to serve during 1951–52:

President: F. E. Wingfield, Muskogee.
Vice-President: W. J. Bishop, Bartlesville.
Secretary-Treasurer: H. J. Darcey, Oklahoma City.

H. J. Darcey,
Secretary-Treasurer

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Collapsible Air Diffuser—The Colaflex diffuser, a new type of equipment for diffusing air or other gas into liquid to produce agitation or to effect absorption, is announced in Bulletin 6530. A flexible, collapsible, special fabric element is readily cleaned by simply reversing flow through the element.—Infilco, Inc., Box 5033, Tucson, Ariz.

Belt Conveyor Idlers—Bulletin 51–81 contains information on the latest design and developments in Rex Belt Conveyor Idlers and Machinery. Also included is maintenance information and a detailed description of zipper bunker seals and belt conveyor trippers.—Chain Belt Co., 1600 W. Bruce St., Milwaukee 4, Wis.

Roller Chains—Bulletin 51–2 describes Baldwin-Rex Double-Pitch Roller Chains, of both drive and conveyor types, and gives specifications and engineering data.—Chain Belt Co., 1600 W. Bruce St., Milwaukee 4, Wis.

Vibrating Screens—New 20-page Book 2377 on dry and liquid vibrating screens tells how to select screen, screen cloth, and appurtenances, and gives specific engineering data. Many installations for waste treatment are included as illustrations.—Link-Belt Co., 307 N. Michigan Ave., Chicago 1, Ill.

Non-Clogging Spray Nozzles—New 4-page Folder 2386 on Non-Clogging Spray Nozzles for use in cleaning all kinds of materials, screens, etc., gives installation data and application hints. Among the many suggested uses is as scum skimmers in settling and flotation tanks.—Link Belt Co., 307 N. Michigan Ave., Chicago 1, Ill.

Explosion-Proof Motors—A new bulletin (No. 1629) gives construction and application features of totally-enclosed motors for both non-explosion-proof and explosion-proof motors.—U. S. Electrical Motors, Inc., 200 E. Slauson Ave., Los Angeles 54, Calif.

Cylinders and Valve Actuators—Pneumatic and hydraulic actuators for valves and process equipment are described in new Bulletin No. 152.—Ledeen Mfg. Co., 1600 South San Pedro St., Los Angeles 15, Calif.

Incinerators—New Bulletin 111B contains descriptive material and typical installations of mechanically stoked incinerators for rubbish and sludge.—Morse Boulger Destructor Co., New York 17, N. Y.

Process Equipment—New Bulletin No. G50 gives data on various process equipment for sewage and waste treatment, including carbon dioxide equipment, sludge and scum collectors, oil reclaimers, paper save-alls, clarifiers, flocculators, mixers, mechanical and diffused air activated sludge aerators, trickling filter distributors, and sludge digesters and appurtenances.—Walker Process Equipment, Inc., Aurora, Ill.

Motor Backstops—Prevention of reversal of rotation of electrical motors, by backflow through a pump or by accidental current reversal, is prevented by an ingenious ball backstop (Ballomatic) described in a new insert for the Vertical Hollowshaft bulletin.—U. S. Electrical Motors, Inc., 200 E. Slauson Ave., Los Angeles 54, Calif.

High-Rate Filter Cloths—Two new FEON dynel filter fabrics designed to give higher flow rates than previously available synthetic fabrics are announced in a new bulletin. The new cloths are claimed to closely resemble in appearance, texture, and filtering characteristics, cotton cloths of similar weaves. The material is virtually unaffected by a wide range of acids, bases, and salts, and can be used at temperatures up to 250° F. in pressure, vacuum, centrifuge, or dry filtration equipment.—Filtration Fabrics Division, Filtration Engineers, Inc., 155 Oraton St., Newark 4, N. J.

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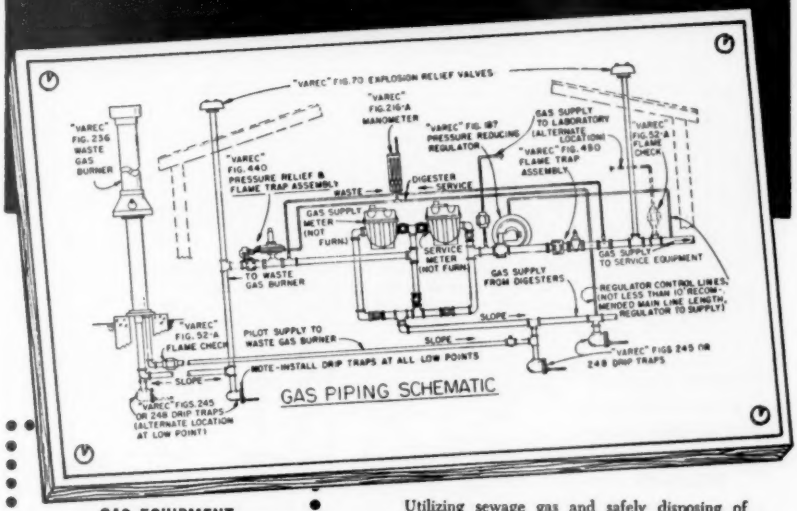
"VAREC" FIG. 70 EXPLOSION RELIEF VALVES
"VAREC" FIG. 236 WASTE GAS BURNER
"VAREC" FIG. 216-A MANOMETER
"VAREC" FIG. 87 PRESSURE REDUCING REGULATOR
GAS SUPPLY TO LABORATORY (ALTERNATE LOCATION)
"VAREC" FIG. 52-A FLAME CHECK
"VAREC" FIG. 450 FLAME TRAP ASSEMBLY
"VAREC" FIG. 440 PRESSURE RELIEF & FLAME TRAP ASSEMBLY
WASTE
DIGESTER SERVICE
GAS SUPPLY METER (NOT FURN.)
SERVICE METER (NOT FURN.)
GAS SUPPLY TO SERVICE EQUIPMENT
TO WASTE GAS BURNER
GAS SUPPLY FROM DIGESTERS
REGULATOR CONTROL LINES (NOT LESS THAN 10' RECOMMENDED MAIN LINE LENGTH, REGULATOR TO SUPPLY)
"VAREC" FIG. 52-A FLAME CHECK
PILOT SUPPLY TO WASTE GAS BURNER
SLOPE
SLOPE
"VAREC" FIGS 245 OR 248 DRIP TRAPS
NOTE-INSTALL DRIP TRAPS AT ALL LOW POINTS
SLOPE
"VAREC" FIGS. 245 OR 248 DRIP TRAPS (ALTERNATE LOCATION AT LOW POINT)
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"VAREC" Fig. No. 440

b. **FLAME TRAP ASSEMBLY**
"VAREC" Fig. No. 450

c. **FLAME CHECK**
"VAREC" Fig. No. 52A

d. **EXPLOSION RELIEF VALVES**
"VAREC" Fig. No. 70-1

e. **WASTE GAS BURNER**
"VAREC" Fig. No. 236

f. **DRIP TRAPS**
"VAREC" Fig. No. 245 (automatic)
"VAREC" Fig. No. 248 (hand operated)

g. **MANOMETERS**
"VAREC" Fig. No. 216A

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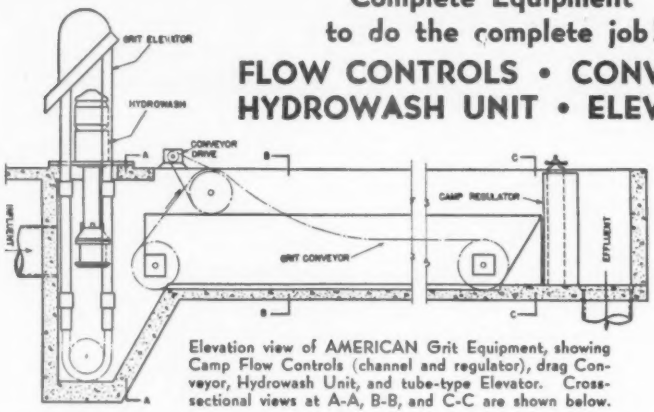

Elevation view of AMERICAN Grit Equipment, showing Camp Flow Controls (channel and regulator), drag Conveyor, Hydrowash Unit, and tube-type Elevator. Cross-sectional views at A-A, B-B, and C-C are shown below.

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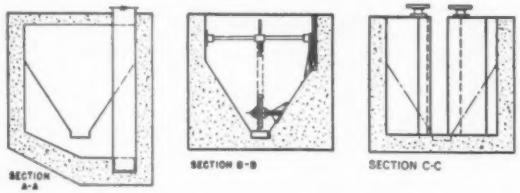

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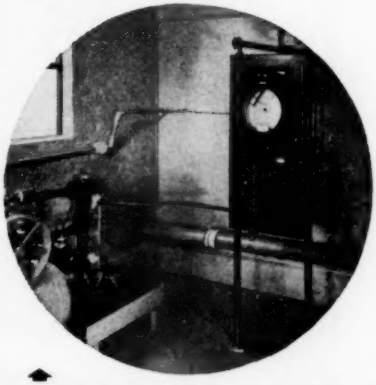

Foxboro pH Controller in pump house at Mansfield Bleachery regulates flows into the mixing basin.

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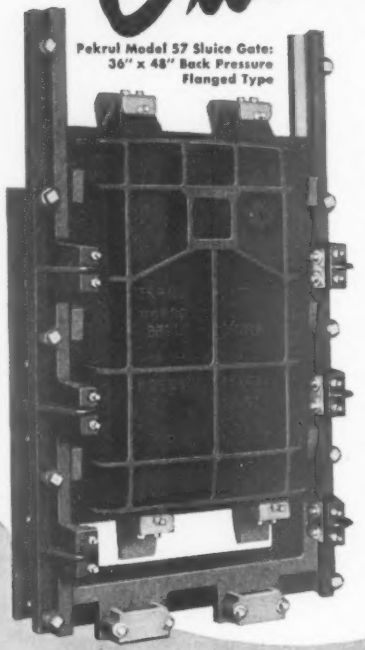

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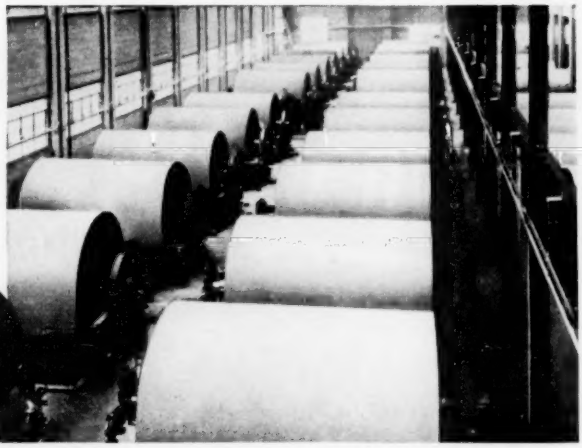

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The West-Southwest Treatment Works of the Chicago Sanitary District is the largest sewage treatment plant in the world. Here, the huge volume of industrial and residential waste from the heavily populated metropolitan area has presented sewage engineers with an unparalleled challenge. Progressively, the Chicago Sanitary District has met that challenge. Starting twenty years ago with installations of continuous vacuum filters for activated sludge, Sanitary District engineers have developed the most exacting specifications and rigid requirements for filter designs and performance . . . culminating in the installation of 66 Conkey Rotary Drum Vacuum Filters for this largest single installation in the sewage field.

These Conkey units incorporate:

Polystyrene plastic cloth backing drainage plates for long cloth life and low maintenance.

Floating cake discharge scraper.

Protective coatings for filter components.

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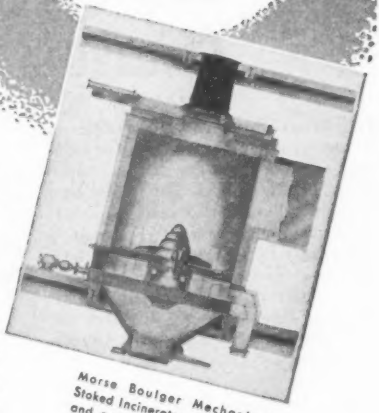

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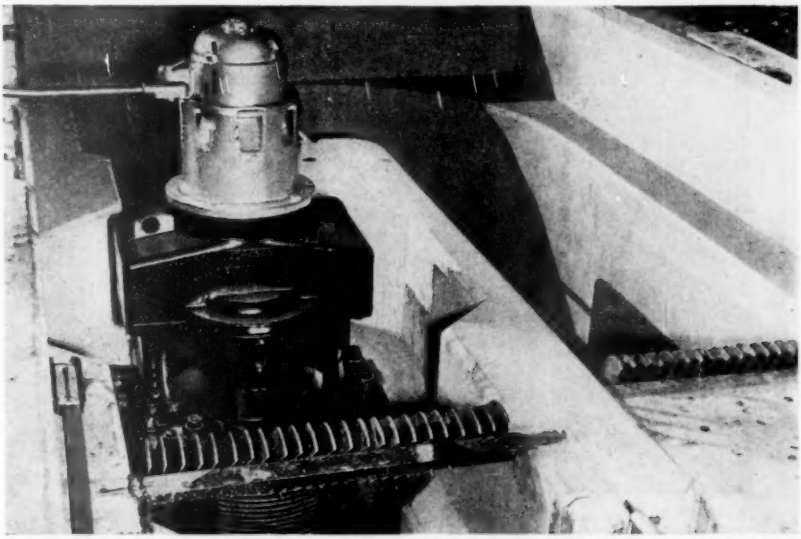

WORTHINGTON COMMINUTOR IS EASILY INSTALLED TO HANDLE LARGE VARIATIONS IN FLOW like this one at the Madison-Chatham (N. J.) Sewage Treatment Plant. Maximum wet-weather flows are occasionally as high as five times the average design dry-weather flow. An overflow screen is installed on top of the comminutor to screen flows in excess of the comminutor's capacity. Screenings are later raked down into the comminutor during period of normal flow. The overflow screen makes the comminutor independent of the by-pass on right which may later be used as a channel for a second comminutor. Plant Superintendent is Edward P. Molitor.

Madison-Chatham, N. J., installation proves adaptability of Worthington COMMINUTOR

Typical example of the adaptability of the Worthington comminutor is the story of this installation at the Madison-Chatham Joint Meeting Sewage Treatment Plant in Chatham, N. J.

Engineers everywhere especially like the Worthington comminutor because:

- It can be readily installed in new or existing straight-flow rectangular channels.
- Cutter-racks are quickly removable for sharpening or replacement.
- It may be flooded without damage because it's protected by a mercury seal.

Worthington's public works specialists are ready to work with your community's engineer in solving screening problems—as well as other problems in sewage, water works, or municipal power generation. Write for Comminutor Bulletin W-2010-B3. Worthington Corporation, formerly Worthington Pump and Machinery Corporation, Public Works Division, Harrison, N. J.

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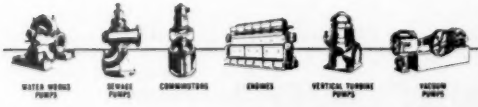

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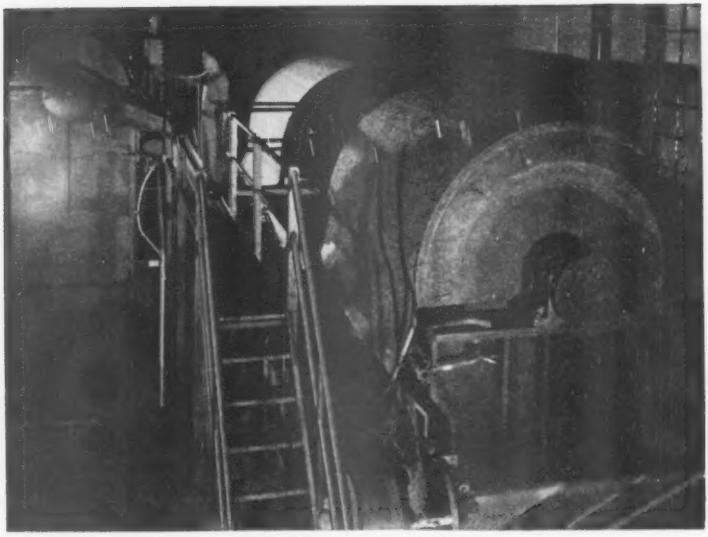

Two Eimco Filters in Sewage Plant, Waterbury, Conn. Plant construction directed by H. C. Whitlock, supervised by W. N. Kunsch.

NEW SEWAGE PLANT DEWATERS SLUDGE

—and **Everdur** is chosen for the Eimco Vacuum Filters that do the job

MALCOLM PIRNIE, consulting engineer of New York, designed the sewage plant for Waterbury, Conn. to treat domestic sewage mixed with industrial waste. Vacuum filtration and incineration were advised.

Eimco Corp. supplied two continuous rotary filters with swing agitators. Everdur* was chosen to resist the corrosive sludge effluent. All woven wire screens (5 x 5 mesh x .063" gage), division strips, bolts, nails and screws are Everdur.

Strength, corrosion resistance, good working and welding properties recommend Everdur as a durable alloy. In handling industrial wastes, corrosion problems are complicated. For the proper Everdur Alloy for your application write our Technical Department. The American Brass Co., Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont. 52152A

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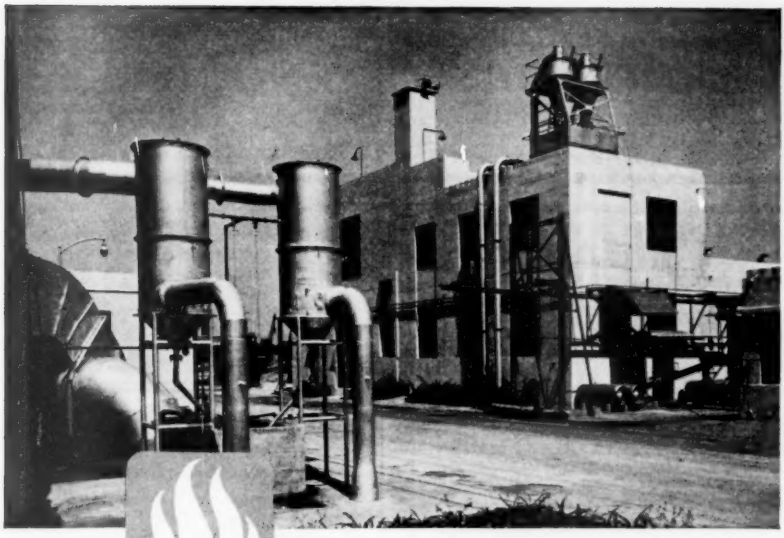

New C-E Flash Drying Unit at San Diego Extension

...almost triples capacity of original installation

When San Diego's Bayside Sewage Treatment Plant went into operation in 1943 it was equipped with a C-E Raymond Flash Dryer Unit designed to handle 63 tons of filter cake per day. Shortly after the war plans were made to increase the capacity of the plant to meet the growing needs of the San Diego area.

In June of 1950 the San Diego Extension went into operation, serving an equivalent population of more than 500,000. The C-E Flash Dryer Unit at this extension handles almost double the amount of filter cake as the original unit — 110 tons per day. The evaporation rate of the second unit is about 5000 pounds per hour.

San Diego Extension is typical of C-E Raymond System installations, now in service in virtually all parts of the country, meeting the varying requirements of both large and small communities. They are flexible in layout, highly efficient and thoroughly reliable; they provide for maximum utilization of waste heat.

The services of C-E specialists are available to assist you in finding the best solution to your sludge problem. Get in touch with the office nearest to you for prompt attention. B-525A

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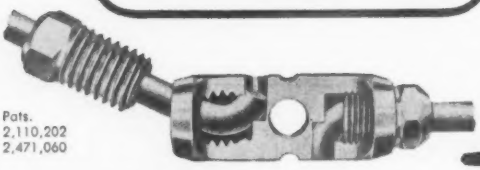

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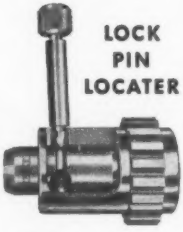

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INDEX TO ADVERTISERS

	Page
American Brass Company	252a
American Car & Foundry Company	220a
American Concrete Pipe Company	234a
American Well Works	244a
Bailey Meter Company	224a
Builders-Providence, Inc.	230a
Cast Iron Pipe Research Association	226a
Chicago Pneumatic Tool Company	211a
Clow, James B. & Sons	212a
Combustion Engineering—Superheater, Inc. (Flash Dryer Div.)	258a
Dorr Company, The	232a
Economy Pumps, Inc. (C. H. Wheeler Mfg. Co. Div.)	231a
Fairbanks, Morse Company	235a
Flexible Sewer-Rod Equipment Company	260a
Forboro Company, The	243a
General American Transportation Corp., Process Equipment Div.	140a
Wiggins Gasholder Div.	128a
Gruendler Crusher & Pulverizer Company	242a
Inertol Company, Inc.	238a
Infilco, Incorporated	236a
Jeffrey Manufacturing Company	136a
Link-Belt Company	252a
Morse Boulger Destructor Company	232a
Morse Brothers Machinery Company	240a
Pacific Flush Tank Company	230a
Simplex Valve & Meter Company	221a
Snow Irrigation Supply Company	240a
U. S. Pipe & Foundry Company	241a
Vapor Recovery Systems Company	245a
Walker Process Equipment Company, Inc.	249a
Wallace & Tiernan Company, Inc.	Back Cover
Welsbach Corporation (Ozone Processes Div.)	227a
Worthington Corporation (Public Works Div.)	251a
Yeoman Brothers Company	222a

DIRECTORY OF ENGINEERS, pp. 254a–259a

Albright & Friel, Inc.
Alvord, Burdick & Howson
Baker, Michael, Jr., Inc.
Baxter & Woodman
Beta, W. H. & L. D.
Black & Veatch
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Burgess & Niple
Burns & McDonnell
Camp, Dresser and McKee
Capitol Engineering Corporation
Chester Engineers, The
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Danon & Foster
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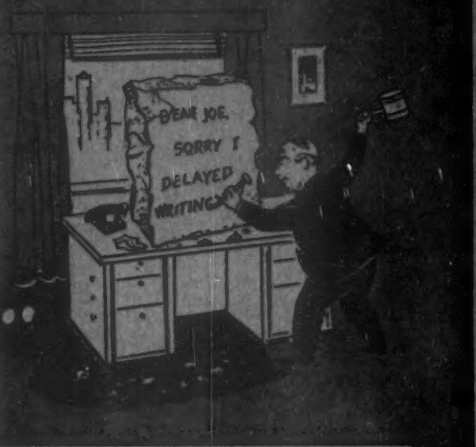

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S-71